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MODELLING PROTEIN AND FAT GAINS IN GROWING PIGS EXPOSED TO LOW ENVIRONMENTAL TEMPERATURE

by

© P. A. Phillips

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Modelling Protein and Fat Gains in Growing Pigs Exposed to Low Environmental Temperature

submitted by P.A. Phillips

in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Animal Science

ABSTRACT

A three-dimensional graphical energy partition model was developed relating protein and lipid retention in growing pigs (45 to 75 kg) to dietary energy intake and environmental temperature. The model can be used to predict animal heat production at each feeding level, neutral environmental temperature at each feeding level and incremental energy conversion efficiency over a range of feeding levels and environmental temperatures.

To validate the model predictions a feeding trial was undertaken to determine the effects of low temperature on rates of protein retention and weight gains in growing-finishing pigs (45 to 80 kg). Two groups of eight individually-caged pigs (female, Yorkshire cross) were exposed alternately for 15-day periods to 21° and 6°C. Half the pigs in each group had ad Libitum access to the rations while the other half were restricted to 100 $g/kg^{0.75}$ of feed intake per unit metabolic body weight. From regressions of liveweight versus time for the last 10 days of each period, low temperature (6°C) was found to reduce average daily gain by 2.3% per °C below the rate of 792 g/d measured at 21°C. From nitrogen balance data, protein retention rates were found to decrease by 1.2% per °C below the rate of 149 $kJ/(d.kg^{0.75})$ measured at 21°C. The ratio of protein gain to total weight gain was, on average, 25% larger at 6°C, compared to that measured at 21°C, indicating leaner growth at low temperature.

A comparison of the results of the feeding trial with the values predicted by the energy partition model indicate protein gain, protein gain/total weight gain, and average daily gain values obtained in the feeding trial were within 5% while estimated lipid deposition rates were within 21% of the model predicted values.

While exposed to the lower temperature(6^{o}C), the digestibility of ration dry matter, energy, and nitrogen(78.2%, 77.0%, 74.7%) was significantly lower than when pigs were exposed to 21^{o}C (80.8%, 79.9%, 79.4%). Increasing body weight from 45 to 80 kg had no effect on digestibility. Although restriction of feed consistently resulted in higher digestibility values for dry matter, energy, and nitrogen, as compared to the ad Libitum fed pigs, feed level effect did not reach statistical significance.

From bi-daily weighings, estimates of transitory body weight changes were obtained for restricted-fed pigs at each abrupt temperature changeover. With each temperature decrease(21^{o} to 6^{o}C), there was a temporary loss in body weight of 4±4%. However, with each temperature increase (6^{o} to 21^{o}C), body weight increased 4±0.8%. Estimated changes in weight of gutfill were derived from weight of feces collected during the five days after each temperature changeover for restricted-fed pigs. These values were highly correlated(r=0.92) with the transitory weight changes. Regression analysis indicated changes in gutfill could be responsible for about 55% of the observed weight changes.

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SECTION A

INTRODUCTION

Over the past two decades, the relationship in growing hogs between level of feeding and their performance at low temperature has been intensively researched (Sorenson, 1961; Seymour et al, 1964; Holmes and Mount, 1967; Close et al, 1971; Close,1971; Fuller and Boyne, 1971, 1972; Verstegen et al, 1973; Verstegen and van der Hel, 1974; Gray and McCraken, 1974; Mount, 1976; Close and Mount, 1976a, 1976b, 1976c; Verstegen et al, 1977). Basically the problem is that growing hogs kept at low temperatures reduce their efficiency of feed conversion, viz. more feed is required per unit weight gain. Where restricted feeding is used, this is manifest in reduced weight gains; where pigs are fed ad Libitum, feed consumption increases considerably (Verstegen et al, 1977).

Studies concerned with the effects of cold on animals usually refer to the concept of the zone of thermoneutrality (Mount, 1974): a range of temperature within which the rate of heat output of an animal of given (prescribed) age, size (weight), physiological state and level of feeding is unaffected by changes in ambient temperature. Whether or not heat output is strictly constant is less important than the fact that heat output is minimum relative to temperatures either above or below this zone. Therefore, in order to maximize productive work, animals should be maintained within this temperature range. The temperature that marks the lower bound of the zone of thermoneutrality is known as the lower critical

temperature. Below this temperature the animal is obliged to use feed energy to elevate its rate of heat production so that its body heat content is consistent with the metabolic and physiological functions needed to sustain life. Consequently pigs housed at low temperature convert feed to body gains less efficiently.

Besides the importance of feed conversion efficiency, producers are also encouraged economically to produce pigs with a minimum of excess carcass fat. In the United Kingdom, suggested rates for feeding growing pigs are based on optimizing feed conversion efficiency and carcass quality (A.R.C., 1967). Clearly then, as a decision-making aid in the evaluation of feed and shelter requirements for growing pigs, the concept of the zone of thermoneutrality may be of limited value since it takes no account of possible changes in composition of tissues in the growing pig exposed to low temperature. Therefore the following review of the literature is concerned with the fundamentals of energy utilization by growing animals and the concepts of thermoneutrality, paying particular attention to energy utilization by growing pigs and the effects of exposure to low temperature.

SECTION B

REVIEW OF LITERATURE

Energy Utilization

"Energy studies are concerned with the determination of relative food values; with the influence of various environmental factors, methods of feeding, and combinations of nutrients upon food utilization; and with the efficiency of various animals as converters of food energy." (Maynard and Loosli, 1965).

Although all matters quoted above influence production efficiency of growing pigs, this review gives particular consideration to the efficiency of pigs as converters of food energy and the influence of the thermal environment on energy losses from growing pigs.

Not directly referred to in the above quote are the complex biochemical transformations common to all living organisms, collectively called intermediary metabolism. The stochiometry of these transformations is central to animal production efficiency and although practical feeding methods require little knowledge of intermediary metabolism some introduction to these concepts is desirable for the development of this thesis.

Intermediary Metabolism

During combustion, fuel electrons at high energy level are transferred to oxygen at a lower energy level, resulting in the products water and carbon dioxide together with the release of energy in the form of heat. For example, burning one mole of glucose will yield 6 moles CO_2,6 moles H_2O, and 2800 kJ of heat; burning a mole of palmitate will yield 12000 kJ of heat together with 16 moles CO_2 and 16 moles H_2O. In animals, feeds are also oxidized; the eventual products of combustion (CO_2, H_2O) in the animal are precisely the same as if the metabolite were burned. However, the release of the chemical-bond energy in the animal is very carefully controlled through a great many distinct intermediate steps. Chemical-bond energy from metabolites (feed constituents absorbed into the body such as carbohydrates, amino acids, lipids) are chemically transformed via an energy currency unit such as Adenosine-Tri-Phosphate (ATP) for subsequent use in, for example, biosynthetic work and transport of ions. Large numbers of enzymes play an essential role in this controlled release of energy.

Just as different types of fuel differ in their heats of combustion, various types of metabolites differ in their theoretical yield of high energy chemical bonds such as in ATP. Where carbohydrates and lipids are utilized by non-ruminants, about 85 kJ of metabolized nutrients are required per mole of ATP formed (Milligan, 1971). However, because of the need for deamination, ATP yield from protein may be 10 to 20% less. Energy harnessed in the terminal phosphate bond of ATP can be used to carry out chemical work in the body such as maintenance of vital physiological functions and production of new tissues.

Research has outlined the probable biochemical mechanisms for the synthesis of new tissues from precursors derived from ingested feeds. Because of the importance of tissue production in growing animals, the term " nutritional efficiency " arises. Nutritional efficiency is the ratio of the total energy contained in newly produced tissues to the total energy input comprising the energy of the individual precursors and the energy linking them together. On this basis, the theoretical production efficiency of protein from individual amino acids would be about 89%, while the synthesis of palmitate from acetate precursors would be less efficient at about 71% (Milligan, 1971).

Studies with whole animals however, have indicated actual nutritional efficiencies to be in the order of 10 to 20 % lower than might be expected from theoretical predictions. Additional energy costs not considered in predicted biosynthetic pathways such as transport of nutrients used in synthesis, amino acid modifications, protein turnover and maintenance of ion gradients, could account for this discrepancy (Milligan, 1971).

Fortunately the assessment of the energy needs of animals does not require consideration of the intermediary energy transformations. The energy sum of the intermediary transformations is equivalent to the heat of combustion of the ingested fuel less the energy losses in the feces, urine, and combustible gases (Law of Hess). This difference, in growing animals, is apparent as heat energy and energy retained in the body and is referred to as metabolizable energy.

Obviously, energy retained is of more interest in animal production than is heat loss. However, the fate of heat energy incident to metabolism is of vital importance to homeotherms, including farm livestock and poultry. All or a portion of this heat loss is needed to maintain a relatively constant body heat content when the animal is exposed to various ambient temperatures. Indeed, in very cold regions, additional insulation must be provided to animals in the form of buildings. Knowledge of rates of heat production by animals is important to the sound design of such shelters. Therefore some of the basic principles of heat loss and animal thermal balance are discussed in the next section.

Heat Loss and Animal Thermal Balance

The necessity of controlling heat production (Q_m) and heat loss (Q_t) such that body temperature is confined within narrow limits is a matter of survival to homeotherms. Over time, the following balance must be preserved:

$$Q_m = Q_t \quad \cdots\cdots\cdots\cdots \quad 1$$

Often, however, before reaching the point where survival is in question, less severe environmental challeges can cause discomfort and diminish production. These sub-lethal stresses are not reflected in Equation 1, but may be of practical importance.

Methods for the identification and definition of acute or chronic thermal stresses in livestock and poultry, have been sought by many researchers and have been discussed in reviews by Burton and Edholm, 1955; Blaxter, 1962; and Mount, 1968). Figure 1, taken from these references, schematically represents a section of an animal trunk and serves as a useful model for reviewing the principal avenues of heat loss from animals.

Starting from the body core, nominally at temperature T_b, and following the outward transfer of heat to the environment, there is first a significant temperature gradient to the membrane surface (e.g. skin or respiratory tract tissue) at temperature T_s. Under warm conditions, the blood may carry much of this body heat to very near the membrane surface, thus minimizing the resistance of body tissues to heat flow and accelerating heat losses by increasing skin temperature. Under cold conditions the blood flow to the membrane surface may be severely restricted (vasoconstriction) and heat loss is minimized since the outer tissues are able to provide resistance to heat flow. Heat transferred to the membrane surface will be a function of surface area (A) and temperature gradient between the core and the surface at temperature T_s; that is,

$$Q_t = A \ H_k \ (T_b - T_s) \ \ldots\ldots \quad 2$$

where the heat transfer coefficient, H_k, can be regarded as a variable which, to an extent, can be controlled by the animal.

Symbols:

T_a , ambient temperature
T_{ss}, surrounding surface temperature
T_{os}, outer surface temperature
T_s, skin temperature
T_b, body temperature
Q_t, total heat
Q_s, sensible heat
Q_L, latent heat
Q_c, convective heat
Q_r, radiative heat
e_a, air vapor pressure
V, air velocity

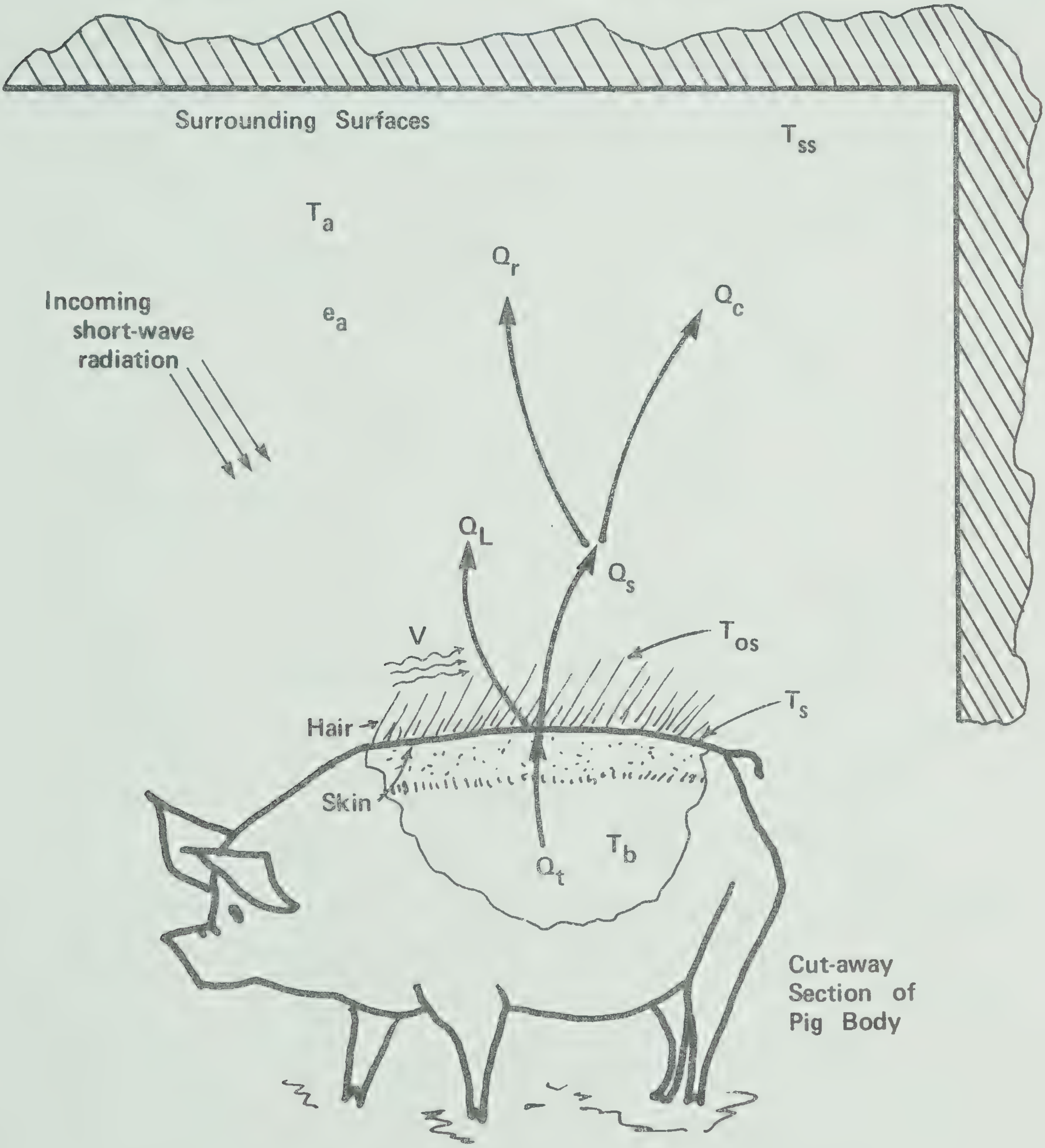

Figure 1. Schematic depicting the transfer of heat from the animal body to the surrounding environment.

At all membrane surfaces such as the skin and respiratory tract tissue, there is usually some evaporation of moisture. This isothermal avenue for heat loss is related to the change in state of water and is referred to as latent heat loss (Q_L) to be distinguished from sensible heat loss (Q_S) which requires temperature gradient. Taking an extreme case where ambient temperature would happen to be equal to body temperature, latent heat losses must account fully for all metabolic heat production if body temperature is to remain constant. In all cases the following balance must hold true:

$$Q_t = Q_L + Q_S \quad \ldots\ldots\ldots\ldots \quad 3$$

Sensible Heat Loss.

Reference to Figure 1 indicates a layer of hair providing insulation or resistance to heat transfer from the skin surface to the air. For some animals, such as the pig, little or no such insulation exists. However, where present, hair tends to entrap air through which heat must be conducted. The resistance to heat flow will be proportional to the temperature gradient from the skin surface to the hair outer surface at temperature T_{OS}; that is,

$$Q_S = A \ H_h \ (T_S - T_{OS}) \ \ldots\ldots \ 4$$

Again, within limits, the animal can control the heat transfer coefficient, H_h, by bristling (piloerection) of the hair coat and increasing the volume of entrapped air or by behavioral changes. If given

time for adaption, weight of hair coat can be increased substantially by new growth (Webster, 1969).

Normally, sensible heat is transferred from the animal outer surface to the surrounding environment by radiation (Q_r) and convection (Q_c) in proportions determined by the air temperature, mean radiant temperature, and relative air movement such that:

$$Q_s = Q_r + Q_c \quad \ldots\ldots\ldots \quad 5$$

Both modes of heat transfer are complex and are governed by different laws.

Where temperature differences exist between a surface and a fluid, heat is said to be transferred from the body to the fluid by convection. Actually heat is conducted across a thin boundary layer of stagnant fluid which adheres very closely to the surface. The thickness of this film, and therefore its insulation value, decreases as fluid movement against the surface increases. From theoretical development the convective heat transfer coefficient, H_c, can be shown to vary directly in proportion to the velocity, V ,and inversely in proportion to the diameter, D, for cylindrical objects, as follows:

$$H_c = \text{Constant}(V_a \; D_{a-1}) \;\ldots 6$$

Values in the literature for the exponent "a" usually range between 0.4 and 0.6. Therefore, H_c varies inversely with the diameter so that the

coefficient would be smaller for the main body as opposed to one of its limbs. Thus, the convective heat losses per unit area can be expressed in terms of H_c and the temperature gradient between the outer surface (T_{os}) and the air at temperature T_a, as follows:

$$Q_c = H_c(T_{os} - T_a) \quad .... \; 7$$

By virtue of its absolute temperature (T_k in ^oK), a body emits heat as electromagnetic waves according to this relationship:

$$Q = EPT_k^4 \quad .... \; 8$$

where E = emissivity

P = Stefan - Boltzmam constant

On the basis of the length of wave, a distinction is made between solar radiation (short-wave) from the sun, and infrared radiation (long-wave) from surroundings objects.

Net radiative heat transferred illustrated in Figure 1 via long-waves, is the difference between that going out to and that coming in from the surrounding environment:

$$Q_r = E_o P T^4_{os} - E_{ss} P \, T^4_{ss} \quad ...9$$

where: E_o and E_{ss} = emissivity of animal outer surface and surrounding surfaces: takes account of configuration of 2 surfaces, their relative size, and inclination with respect to each other.

T_{ss} = mean temperature of surrounding surfaces

Sensible heat transfer from the model outer surface may now be expressed by substituting Equation 7 and 9 into Equation 5:

$$Q_s = H_c(T_{os}-T_a) + E_oPT_{os}^4 - E_{ss}PT_{ss}^4 \text{ ....10}$$

This form of Equation 10 is inconvenient and is usually linearized. This approximation involves the substitution of $T_{os}=T_{ss}+(T_{os}-T_{ss})$ and the use of the first two terms of the binomial expansion:

$$Q_s = H_c(T_{os}-T_a) + 4E_oPT^3_{ss}(T_{os}-T_{ss}) + PT^4_{ss}(E_o - E_{ss}) \text{ ....11}$$

Usually E_o and E_{ss} can be assumed to equal 1 and the expression simplifies to:

$$Q_s = H_c(T_{os}-T_a) + 4E_oPT^3_{ss}(T_{os}-T_{ss}) \text{ ......12}$$

Under confinement conditions the temperature of the surrounding surfaces may often equal air temperature and the two coefficients can be added to give a combined heat transfer coefficient, H_{cr}, such that the form of Equation 7 is maintained. Otherwise, Equation 12 indicates that as T_{ss}

tends to deviate from T_a, more weight must be given to the radiation heat loss component.

Two factors mitigating the above sensible heat losses are changes in posture, which may effect exposed body area , and heat gain from incoming solar radiation. For standing animals conductive heat losses to the ground are small and are normally neglected. Under outdoor conditions, incident solar radiation may be substantial and should be added to metabolic heat production.

Latent Heat Loss.

As mentioned previously, evaporative heat loss is the major physical mechanism for heat dissipation at high ambient temperatures. Evaporative heat transfer principles are similar to those for sensible heat transfer except the driving force is the vapor pressure gradient between the membrane surface (e_s) and the air (e_a):

$$Q_L = A\ H_L(e_s - e_a) \quad \ldots\ldots\ldots\ 13$$

The evaporative heat transfer coefficient (H_L) has properties similar to those already described for the convective heat transfer coefficient (H_c).

It should be pointed out that the accurate determination of variables such as H_h, T_s, and T_o, is in practice, very difficult. Temperatures, as they are symbolized here, would be averages of numerous measurements.

Total Resistance to Heat Loss.

Total heat transfer from an animal will depend partly on the magnitude of the individual heat transfer coefficients described above. Each resistance to heat flow contributes to the overall resistance value according to the very same principles used in summing electrical resistances. Sensible versus latent heat transfer or radient versus convective heat transfer are analogous to resistances in parallel; tissue resistance and hair coat resistance are analogous to electrical resistances in series. Overall H values can be checked in the calorimeter by measurement of Q_t, T_a, T_b and A and solving for H.

The above theoretical review of some basic heat transfer principles, indicates how heat loss is a function of vapor pressure and temperature gradients between the animal body and the environment. The magnitude of these gradients will depend on the rate of heat production by the animal and the environmental properties such as air temperature, air velocity, air relative humidity, and mean radient temperature. At what point then does a particular animal experience environment stress?

The need to thermoregulate implies the existence of a sensory system with feedback control to various thermoregulatory mechanisms. Whether or

not a particular environment is stressful can be determined only in vivo by appropriate measurement of physiological strain that indicates the degree of effort required to maintain thermal balance. Efforts have been made to combine the variables affecting heat balance into one parameter that reflects the net thermal impact of the environment. Where humans are concerned, the objective is to determine zones of comfort while such studies on livestock are aimed at optimizing productivity. Examples of both systems are described below. They are quite similar in that both establish points of equivalent heat loss; however the approaches are quite different.

Wind Chill Index.

The Wind Chill Index (Siple and Passel,1945), developed by measuring the freezing time of water in a plastic cylinder, indicates the combined cooling effect of air movement and air temperature. This index describes convective heat losses, particularly the effects of variables V and T_a, as discussed previously in Equation 6 and 7:

$$Q_c = KV_a D_{a-1}(T_{os}-T_a) \quad \ldots\ldots\ldots \quad 14$$

While there is no biological basis for supposing that the heat loss rates from a cylinder is analogous to those from animals, the predicted relative effects of air velocity and air temperature on heat loss are credible as they were measured mechanically. Although developed for humans exposed to sub-freezing temperatures, the system may be calibrated for any species and have been used for cattle (Petritz and Brokken,1974; Christenson and Milligan, 1974).

Critical Temperature.

The Wind Chill Index simply illustrates the development of a measure of environmental stress without the use of animals. More specific to the problem of optimizing pig productivity at low temperature is the critical temperature method, which is based on energy balance studies with pigs.

Figure 2 depicts schematically the relationship between rate of heat production and environmental temperature as typically observed in calorimetric studies on 60 kg pigs fed twice maintenance (2 M) (Holmes and Close, 1977). The biphasic nature of heat loss rates in response to temperature change may be noted. The response of the sloping left hand portion of this curve is analogous to the expected heat loss from an inanimate object maintained at body temperature. When extrapolated to its downward limit at ambient temperature approximately equal to body temperature (dotted line), the thermostatic demand would vanish to zero. However, the actual "biological" heat loss line breaks horizontally at a point known as the lower critical temperature, corresponding to the minimum rate of heat production from metabolism. Heat loss within this zone of thermoneutrality is controlled, chiefly by evaporation of water as shown (dashed line).

The heat loss rate at temperatures below the lower critical temperature is of particular interest. At this temperature, all physical means available for resisting heat loss have been utilized. Any reduction in temperature, below the critical temperature, must be accompanied by a

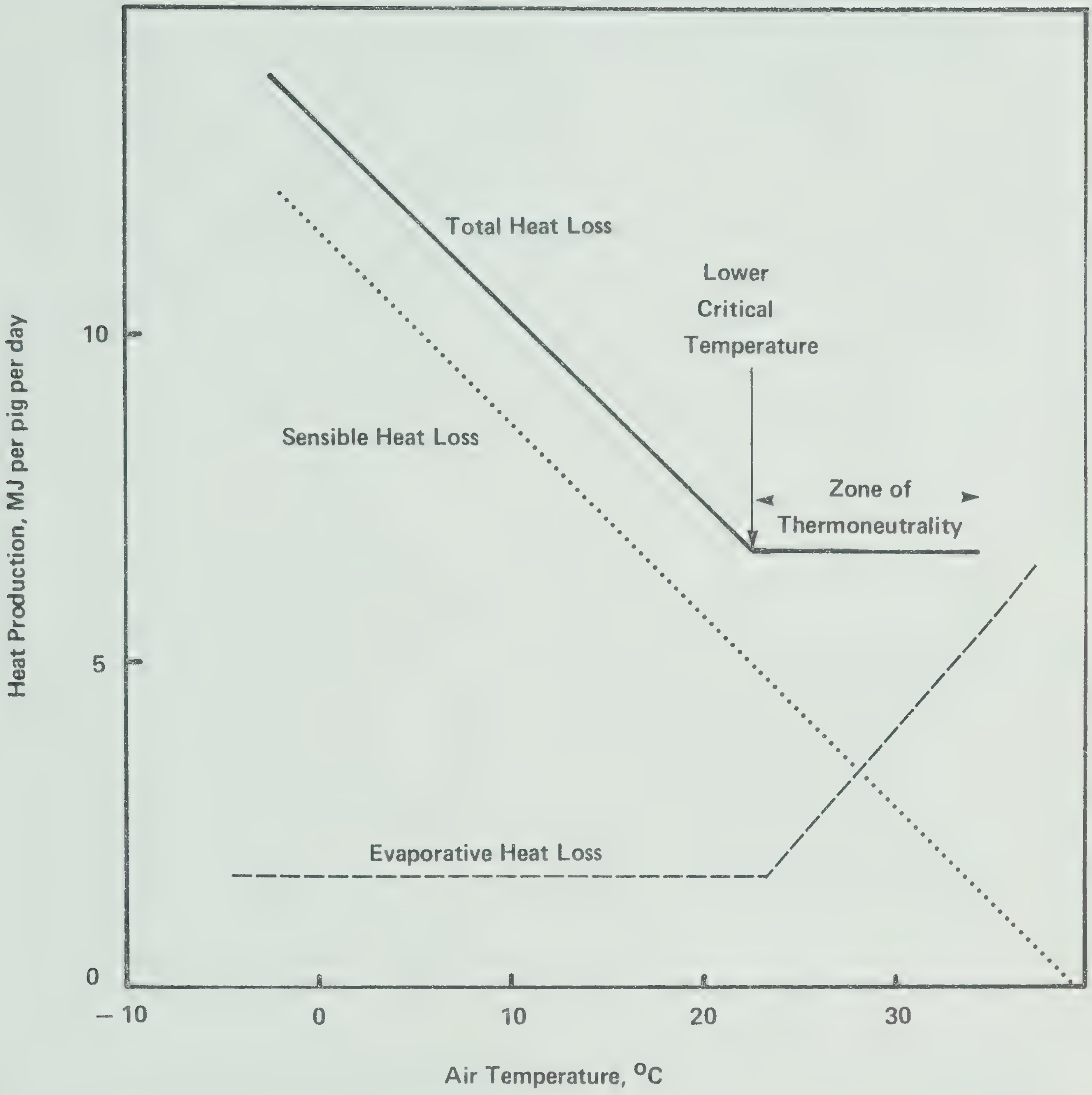

Figure 2. A diagrammatic representation showing the relation between air temperature and the components of heat loss in the pig, for a pig 60 kg liveweight with an ME intake of 2 X Maintenance(from Holmes and Close,1977).

proportionate increase in heat production if body temperature is to be maintained. This additional heat production is entirely sensible heat as may be noted in Figure 2; evaporative heat losses at temperatures below the critical temperature, are constant and reflect mainly respiration losses. Any additional heat production above the thermoneutral heat production must be at the expense of chemical energy ingested in the feed. Therefore, if pigs are fed a restricted amount of feed, the potential energy available for productive work will be diminished. However, if lower critical temperature can be estimated, addition feed allowance can be made to enable the animal to cope with the extra heat requirements at low temperature.

A listing of estimated lower critical temperatures of pigs was devised by Verstegen and Curtis (1978). First consideration is given to factors affecting heat production level as determined from calorimetric experiments, energy intake, body weight, and group size (Table 1). These critical temperatures listed in Table 1 are limited strictly to still-air, concrete floor conditions, where mean radiant temperature is equal to air temperature (i.e. calorimeter conditions).

The next task is to delimit the information in Table 1 to permit estimation of lower critical temperature under the range of enviromental conditions found in practice. Temperature adjustment factors, based mainly on the work of Mount (1976), have been compilied by Verstegen and Curtis as shown in Table 2. These factors can be used to adjust the lower critical temperatures in Table 1 to suite a particular set of

TABLE 1. LOWER CRITICAL TEMPERATURES(^{O}C) IN SINGLE PIGS AND GROUPS OF PIGS OF VARIOUS BODY WEIGHTS(kg) FED AT MAINTENANCE (M = 420 kJ/(d·kg$^{\cdot 75}$), TWICE M, AND THREE TIMES M(FROM VERSTEGEN AND CURTIS,1978).

Kind of Animal	Weight,kg	Feeding Level		
		M	2M	3M
Baby pig(single)	2	31	29	29
(group)	2	27	24	24
Growing pig(single)	20	26	21	17
(group)	20	24	19	15
Finishing pig(single)	60	24	20	16
(group)	60	23	18	13
Finishing pig(single)	100	23	19	14
(group)	100	22	17	12
Sow(thin)	140	25	20	14
(fat)	140	23	18	12

TABLE 2. CHANGE IN LOWER CRITICAL TEMPERATURE(°C) FROM CALORIMETER CONDITIONS FOR PIGS KEPT AT VARIOUS HOUSING, MANAGEMENT, AND CLIMATIC CONDITIONS (FROM VERSTEGEN AND CURTIS, 1978).

Condition	Specification	Weight (kg)	Change in Lower Critical Temperature
Windspeed, m/s			
0.2	Individual pigs	-	+4
0.5	"	-	+7
1.5	"	-	+10
0.45	Group of 9	40	+1.5
Floor			
Concrete vs straw at 10°C		piglet	+8
Concrete vs straw at 30°C		"	+2
Straw	Group of 9	35	-4
Concrete Slats	"	35	+5
Wet surface	"	35	+5 to +10
Draught			
draught	insulation	-	+6
draught	uninsulated(winter)	-	+8
no draught	uninsulated(winter)	-	+2
no draught	uninsulated with straw	-	-4
Radiant Temperature			
+ 1°C	individual	piglet	-1
reflective wall and Ceiling	group	11	-2

environmental conditions. Having estimated the lower critical temperature, the necessary extra heat production required to maintain body temperature can be determined for any sub-lower critical temperature and extra feed allowed according to the rates shown in Table 3 (Verstegen and Curtis, 1978).

Feed Energy Evaluation

This section discusses some approaches to evaluation of feed energy and animal feed energy requirements. The basic goals in assigning energy values to feeds are twofold: on one hand to assess the relative ability of different feeds to furnish energy for body processes and tissues; on the other hand, to permit establishment of the energy requirements for given types of animal production processes (Maynard and Loosli, 1965). In addition to supplying sufficient energy for maintenance and synthetic work, the diet must supply reduced compounds such as amino acids and certain vitamins which are not oxidized. Such compounds as may be incorporated into new tissues, for example, constitute a significant part of the animals energy requirement.

The underlying premise for the establishment of most feed energy systems is that any recognition of losses in metabolism in evaluating a particular feed is better than a purely physical statement of the feed weight or gross energy value (Maynard and Loosli, 1965). Intuitively, one might expect that the introduction of some "biological" factor in computing the feed energy value would be advantageous, in view of the many

TABLE 3. EXTRA HEAT REQUIRED PER °C COLDNESS BELOW THE LOWER CRITICAL TEMPERATURE(kJ/(d·°C) AND EXTRA MEAL EQUIVALENT(g/(d.°C) TO COMPENSATE FOR THIS EXTRA HEAT.(MEAL ME = 12-13 kJ/g)(FROM VERSTEGEN AND CURTIS,1978).

Kind of Animal	Weight kg	Extra Heat kJ/(d·°C)	Meal Equivalent g /(d·°C)
baby pig	2	47	4
growing pig			
-individual	20	163	14
-group	20	160	13
-individual	100	430	36
-group	100	417	35
sow (thin)	140	710	59
sow (fat)	140	408	34

different species of livestock and poultry and the wide range of physiological states which depend, for example, on physical environment, maturity and reproductive status. Figure 3 illustrates the classical energy balance concept for an animal, starting with the heat of combustion in the consumed feed, less various energy losses from animals, such as heat, and finishing with the energy output in production. Several practical methods for measuring feed energy have evolved and each accounts for certain of the losses cited in Figure 3.

Apparent Digestible Energy.

One significant loss which corresponds to the consumption of all feeds, particularly roughages, is fecal energy loss. Apparent digestible energy (DE) of a feed represents the energy of the ingested feed less the energy of the corresponding fecal losses. DE values can be determined by bomb calorimetry. DE is used commonly in America (N.R.C, 1973) and the United Kingdom (A.R.C, 1967) as a basis for recommending energy intake requirements for pigs.

Total Digestible Nutrients.

Feed energy can also be expressed in terms of total digestible nutrients (TDN). TDN values, in kilograms, can be assigned to rations using average digestion coefficients for protein, fat, and carbohydrates, together with proximate analysis data for individual feed constituents. By this method of assessing energy value, protein and carbohydrate are

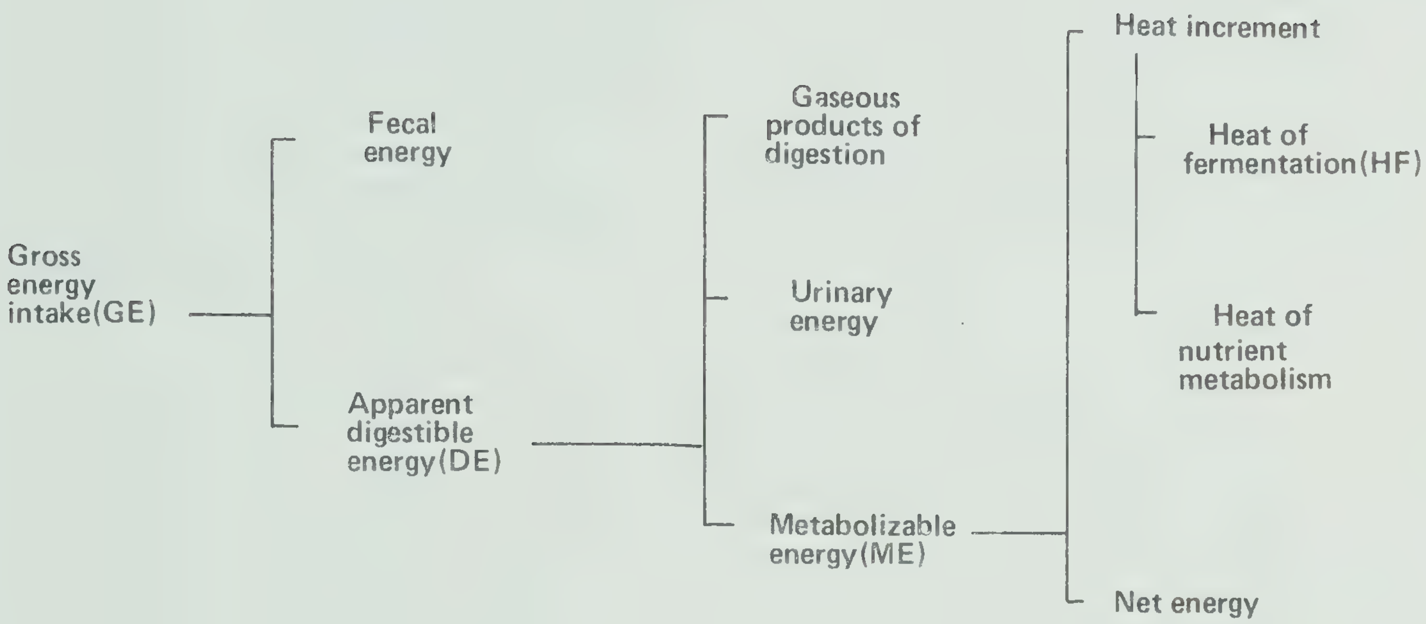

Figure 3. Energy distribution in body processes(Maynard and Loosli,1965).

given energetically equivalent weight while fat is increased by a factor of 2.25 to account for its higher energy value. In giving protein and carbohydrate equal weight, the TDN system inherently accounts for urine energy losses(Maynard and Loosli,1965).

Metabolizable Energy.

The use of metabolizable energy (ME) should be theoretically more precise than DE or TDN in evaluation of the energy content of particular feeds. In addition to accounting for fecal energy losses, ME also accounts for energy losses in the urine and combustible gases. Therefore, ME is a measure of the energy value of a feed in terms of its potential for metabolic work.

In pigs, combustible gas losses are small (about 1% of gross energy intake, Verstegen et al, 1973) and normally are neglected. Also, for many common rations, urine energy losses seem to be fairly constant at about 5% of the gross energy intake. For these reasons, and because ME values have not been determined for many feeds, the DE system is used widely as a basis for recommending energy requirements of pigs. The ME system has been used with success in determination of feeding requirements for cattle however, mainly due to the higher losses of combustible gases in ruminants (A.R.C. 1967).

Net Energy.

The net energy (NE) system, which originated in Germany and has been adopted by many European countries, takes another major conceptual step in that feed energy is expressed in terms of the final product; 1 MJ of NE fed will produce an additional 1 MJ of tissue energy in a growing animal. Thus all the energy losses discussed in the previous feed energy systems, plus heat energy loss due to metabolism, are accounted for in this system.

The NE system is based on experimental work which demonstrates the linearity between ME intake and energy retention (Nehring et al, 1960). Figure 4 depicts this very important finding which originated from studies with cattle. Any significant non-linearity would make necessary the scaling of feed energy values according to level of feeding, which would be a considerable inconvience.

Having established this linearity between energy intake and energy retention, a series of feeding trials were undertaken, to compute regression coefficients for both pure nutrients and common feedstuffs. Multiple regression equations were developed for pigs, based on the ration proximate analysis as the independent variable, as follows :

$$\text{NE,kJ} = 10.03X_1 + 32.23X_2 + 0.04X_3 + 13.67X_4 (\pm 530\text{kJ}) \quad ..15$$

where: X_1= g, digestible crude protein;

X_2= g, digestible crude fat;

X_3= g, digestible crude fibre;

X_4= g, digestible nitrogen free extract.

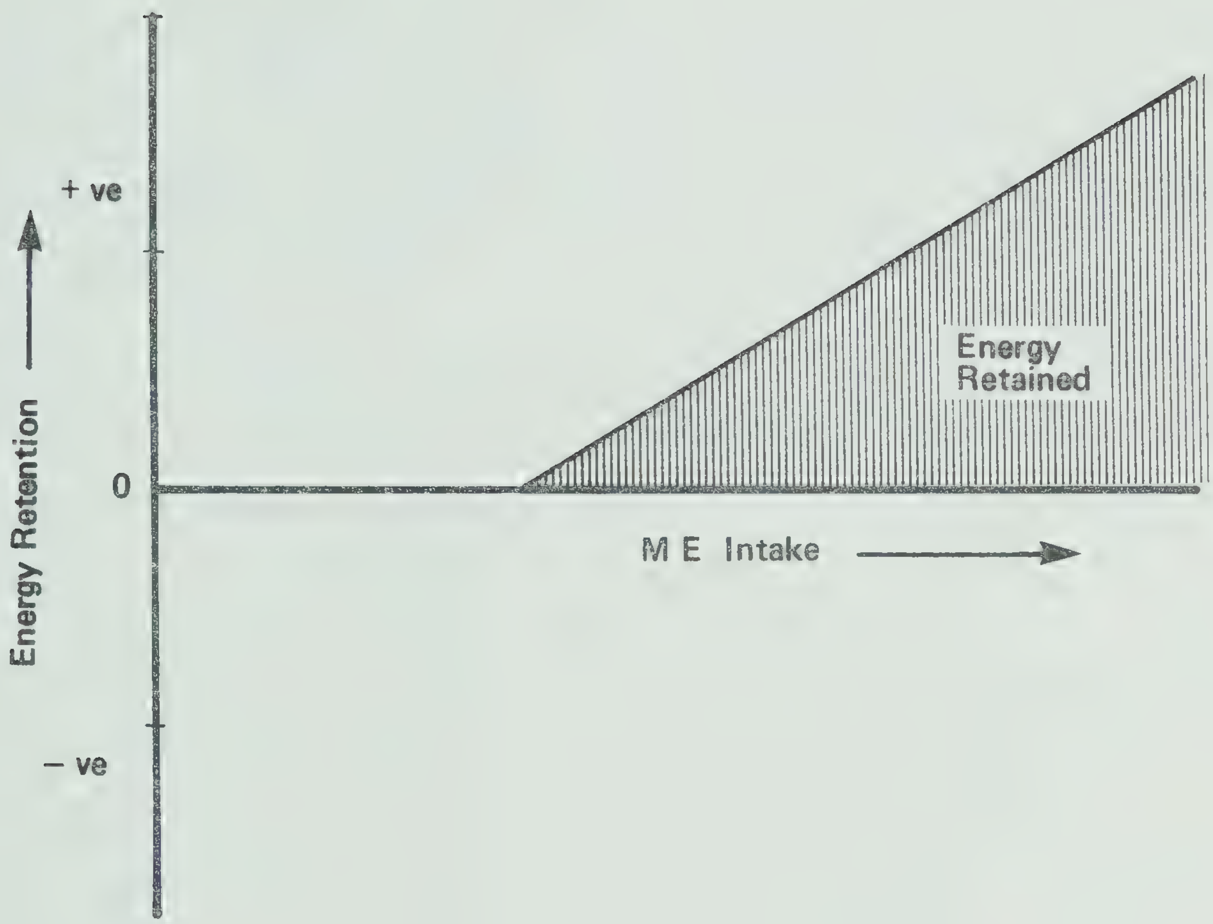

Figure 4. A schematic of the linear energy retention model used by Nehring et al (1960) for the development of the Net Energy feeding system.

A strong resemblance to the TDN system will be noted, with the main difference in the relatively lower net energy value given to protein than carbohydrate (10.03 vs 13.67).

There are several points of interest arising from these discussions, not the least of which is the lack of accounting in any of the feed energy systems for effects of thermal environment. Prior to addressing this problem, however, attention should be given to the fundamental relationship between ME intake and energy retention by growing animals, specifically the linear energy retention model which was basic to the development of the NE system (Figure 4). Indeed, whether the efficiency of conversion of ME to product is a linear or non-linear function of ME intake, the concept of partitioning ME intake has important implications in ration formulation studies, as evidenced by the NE system. Moreover, such a model should be useful to farm building engineering studies, where empirical models predicting animal heat losses are very important.

Energy Partition Models.

While the actual mechanisms for the control of growth are not understood fully , empirical measures of growth, such as body weight or size, are obtained easily. Consequently, certain indicators of normal performance of feeding pigs have evolved. For example, growing pigs usually convert rations such as barley and soybean meal to meat at a ratio

of about 3 to 1 by weight, while producers expect growing pigs fed ad Libitum, to reach market weight (about 90 kg) in about 160 days. Such a view of productivity in pig production, however, is incomplete.

The development of the structural and functional elements in the growing pig are not reflected in an empirical measure such as body weight. Early stages of growth are marked by relatively rapid growth of bone and nervous tissue. At a later stage of development up until puberty, the emphasis is on muscle growth, while towards maturity, there is an increasing tendency to store fat only. Figure 5 (Fowler,1968), is a cumulative model indicating the typical course of these developments. Because there is an economic penalty to the pig producer for carcasses containing excessive fat, pigs generally are slaughtered shortly before puberty so as to achieve the optimum amount of lean tissue growth.

In view of the importance of lean tissue growth, the prediction of protein and lipid retention rates (body carbohydrate content is small and normally is neglected (Maynard and Loosli, 1965)), for a particular energy intake would be desirable. Conceptually, this has been done in two ways. One view suggests that there is a maximum rate of protein retention for a particular animal at a particular age, regardless of energy intake. Any surplus energy, beyond that required to meet the daily maximum protein deposition quota, is converted to fat (e.g. see Whittemore and Fawcett, 1976).

Another concept advanced by Black (1974) suggests that protein and lipid deposition rates are stochiometrically related, and hence an

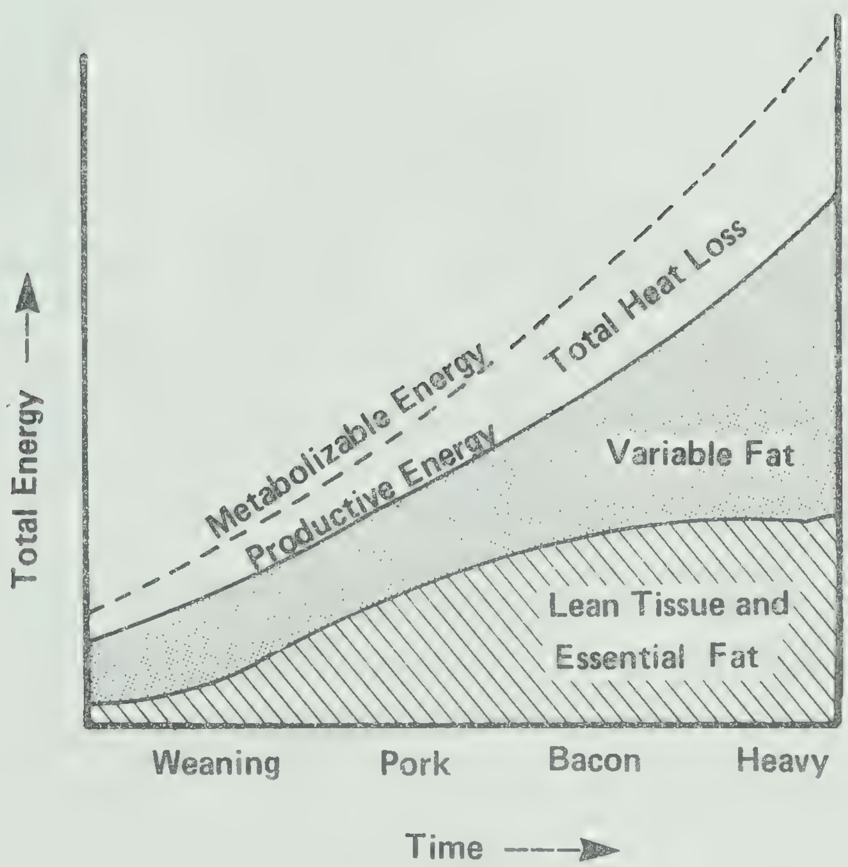

Figure 5. Partition of metabolizable energy in the growing pig on unrestricted feeding. (From Fowler, 1968).

increase in feed energy input must be accompanied by a proportionate increase in protein and lipid deposition. Although the latter concept seems more compatible with the linear energy retention model shown in Figure 4, technically it is very difficult to prove or disprove principally because of the variability in measuring protein deposition rates in pigs.

Fowler (1978) has proposed an energy partition model for pigs along the same lines as that developed for sheep by Black (1974) where energy intake has been partitioned into its various functions of maintenance, protein and lipid deposition (Figure 6). This model predicts the composition of gains at thermoneutrality and is important for several reasons. Firstly it has a conceptual value in relating various growth activities to energy intake; secondly it is of potential practical value for development of ration formulation methods for pigs, such as along the NE lines; thirdly it has potential practical value in the design of farm buildings where predictive models of heat output are useful. Certainly the influence of temperature on the composition of gains should be considered in light of this basic model.

Effects of Low Temperature

Numerous studies concerning the effects of low temperature on the composition of body gains in pigs, have been made but their results are inconclusive. Fuller and Boyne (1971, 1972) scaled up the level of feeding for each reduction in temperature (23^o, 13^o, and 5^oC) to achieve similar rates of gain and found carcasses of pigs grown at low

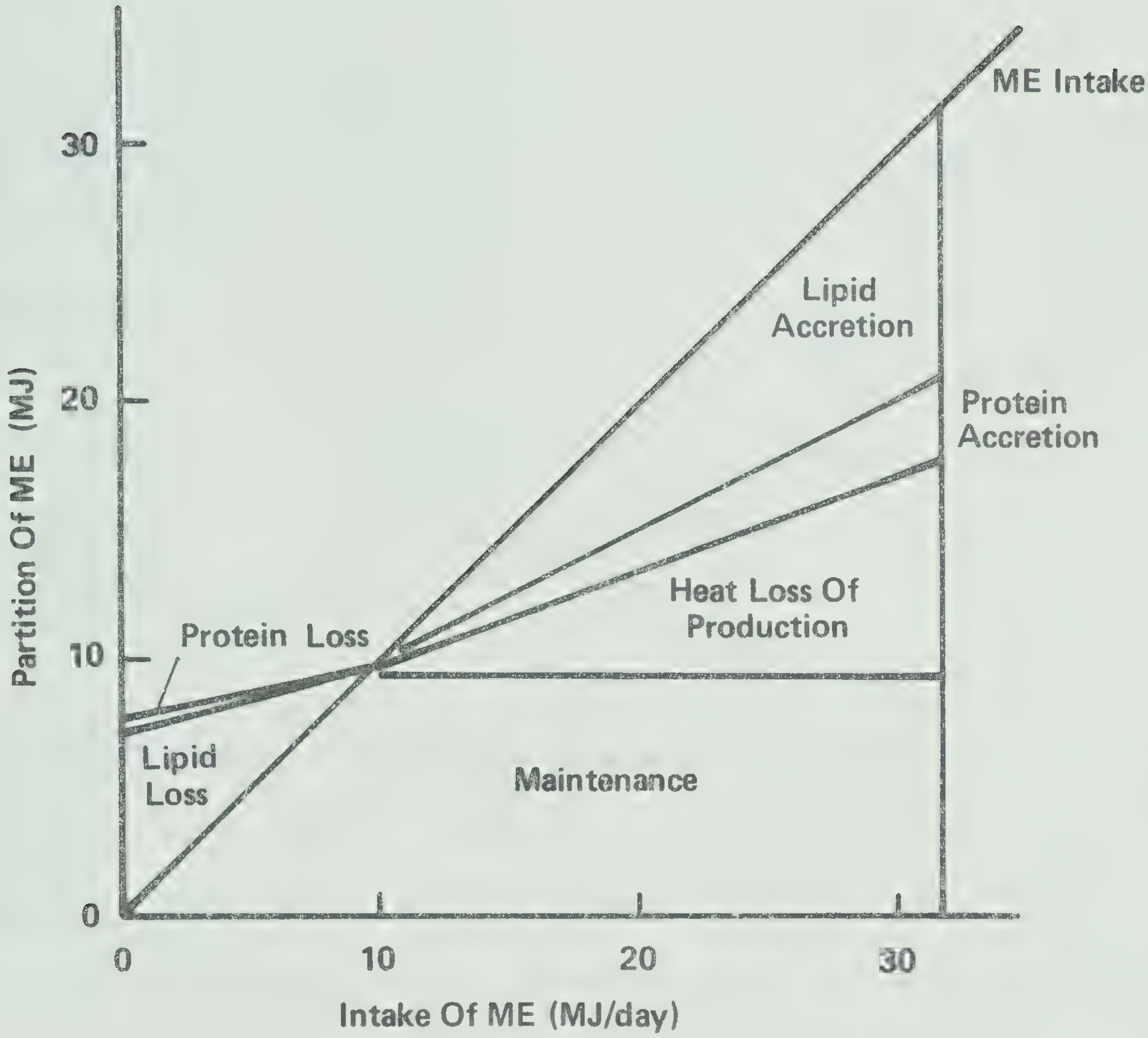

Figure 6 . Partition of metabolizable energy at different rates of daily intake for a pig of 60 kg liveweight, from Fowler (1978).

temperature contained a smaller proportion of protein and a higher proportion of fat. However by adjusting feed intake to a "common" rate, they concluded that reduced growth rate due to cold resulted in no change in body composition.

Verstegen et al (1973) studied protein and lipid rentention and weight gains in groups of pigs fed at different levels at temperatures of 8°C (39, 45 g feed/d. kg) and 20°C (45, 52 g feed/d.kg). Treatments had no effect on weight gains or protein deposition rates. However, at the 45 g feed level the 8°C pigs deposited 30% less fat than the 20°C pigs. They suggest a possible substitution of water for fat in tissue gains to account for the absence of any effect of temperature on weight gains.

Close and Mount (1976) found that protein retention in pigs kept at 10°C and fed three times maintenance (3M) was reduced by 12% and fat retention by 19% compared to rates measured in pigs kept at 20°C. At a feeding level of 2M, protein retention again was reduced by about 12% but fat retention was reduced by about 50%. At a feeding level of 4M, protein and fat retention rates were unaffected by the low temperature of 10°C.

Gray and McCraken (1974) found that a change in temperature from 22° to 15°C caused a reduction in protein deposition rates in pigs of 9% compared to a fat deposition rate reduction of 30%.

Although the results of the above studies suggest that fat deposition rates may respond more to changes in temperature than do protein deposition rates, the result are highly variable indicating that level of feeding is clearly a major complicating factor. Having seen a model (Fowler,1978) which predicts the effect of feed energy intake on the composition of body gains in·the growing pig kept at thermoneutral temperatures a question that now must be asked is how can this model be extended to predict the composition of body gains in pigs kept at low temperatures?

SECTION C

Thesis Objectives

To extend Black and Fowler's energy partition models relating protein and lipid deposition rates in the growing pig to energy intake level to include the influence of ambient temperature.

To validate the extended model through comparison with currently available information as well as against the result of a feeding trial designed specifically to test the protein deposition aspect of the model.

Modelling Rationale

Models are used widely in agriculture. The following relationship may be regarded as a simple example:

$$3 \text{ kg Feed} = 1 \text{ kg Pig} \quad \text{..........} \quad 16$$

This model is used daily by hog growers. The fact that it is not absolutely precise does not undermine its usefulness; indeed, to burden this equation with various correction factors would serve no purpose. In this example, minor refinements can and should be left to the discretion of the user.

Beyond the important need for simplicity and flexibility in any model,the exact format also must be considered carefully. Should the model

be mathematical, physical, graphical, or some other form? The answer to this question will depend on the nature of the problem as well as on the known preferences of other workers in the field.

Finally, the completed model should be validated. This can be done experimentally and/or through comparison with currently available information.

Thesis Format

For the information contained in the remainder of this thesis to be readily accessible, the contents are divided into several sections. A brief explanation of format, therefore, is included at this point.

Following this Section C, containing the statement of objectives, the thesis material is separated into three sections, each distinct and in a format one would expect of a scientific publication. Each section contains its own introduction and review, results, and discussion. The sections appear as follows and correspond to the technical papers noted in parentheses.

Section D: development of an energy partition model relating protein and lipid gains in growing pigs to energy intake and ambient temperature (Phillips and MacHardy, 1979).

Section E: a feeding trial conducted to test the protein deposition aspect of the model (Phillips et al, 1979).

Section F: additional findings from the feeding trial pertaining to digestibility of nutrients and temporary weight changes not reflected in the model (Phillips et al, 1979).

Section G: concluding statements on the main findings of the thesis.

Notes included in all sections refer to the location of appended information desirable for inclusion in a thesis but not appropriate for scientific journal publication. Following the Bibliography, appendix material is provided in three sections: A. Experimental Procedures; B. Raw data from the animal experiment; C. Analysis of variance tables.

Units of Measure

All data are reported in SI units. Energy is expressed in Joules. Feed and hog scales were calibrated in pounds but data were converted to kilograms (kg) at the close of the experiment. Temperature was recorded in degrees Farenheit but converted to degrees Celcius (^{0}C).

Protein has been assumed to have a heat of combustion of 23.5 kJ/g and fat to have a heat of combustion of 39 kJ/g (Whittemore and Elsley, 1976).

The concept of metabolic body size (e.g. body weight to the exponent 0.75, Kleiber, 1961) is used commonly as a basis for comparing adult animals of different species and size. Although unclear whether this exponent is an appropriate adjustment for younger animals such as the

growing pig, this concept has been used by other researchers (Fuller and Boyne, 1971, 1972; Close and Mount, 1976; Verstegen et al, 1973) to express rates of energy and protein retention. In this thesis, therefore, rates of retention of energy, protein, and lipid, have been expressed per kilogram of body weight to the 0.75 exponent.

SECTION D

A MODEL

Introduction

In the sciences of nutrition and meat production, growth can be measured conveniently in terms of the accumulation of energy. In animals, this energy is predominantly in protein and lipid. Although there are many dimensions to growth, the relationship between energy retained as protein and fat (fat is about 85% lipid) is of major importance in the formulation of rations. Therefore, empirical models describing energy retention versus energy intake are the basis of ration formulation.

Blaxter (1962) has reviewed the classical linear energy balance models used for predicting energy retention. Kielanowski (1965) used linear statistical methods to partition heat output arising from growing animals into the energy oxidized for maintenance, protein deposition, and lipid deposition. More recently, Black (1974) and Fowler (1978) have developed models in which energy intake has been partitioned into protein, lipid, and heat energy. The model for pigs shown in Figure 6 predicts the response of protein and fat deposition rates to increasing metabolizable energy intake (Fowler, 1978).

Studies with sheep (Graham et al, 1959) and pigs (Close and Mount, 1970) have shown that, with exposure to lower temperatures, animals that were in the zone of thermoneutrality, where body heat production rate is

dependent on level of feeding, must increase heat production rate in order to maintain body temperature. At the lower limit of the thermoneutral range, called the lower critical temperature (see Figure 2), ME which might have been used for the production of new tissues is diverted instead into increased heat output, thus resulting in reduced growth (Holmes and Close, 1977).

The above findings are useful but give no indication of the effects of low temperature on the composition of body gains in growing pigs. This section is concerned with the extension of the presently available Fowler model to predict rates of protein and lipid retention and heat loss from growing pigs exposed to low environmental temperatures.

Development of Low Temperature Model

Starting with the basic Fowler model as shown in Figure 7, the changes in intake energy utilization induced by lowering the environmental temperature are shown in Figures 8, 9, and 10.

The biochemical reactions associated with the maintenance state result in heat production. This heat is utilized by the pig to maintain body temperature through the environmental temperature range usually referred to as 'the zone of thermoneutrality'. The lower temperature limit of this zone for a hog at maintenance feed intake is plotted as T_0 in Figure 7, while E_m indicates the maintenance metabolizable energy intake. Any intake energy increment above E_m, at

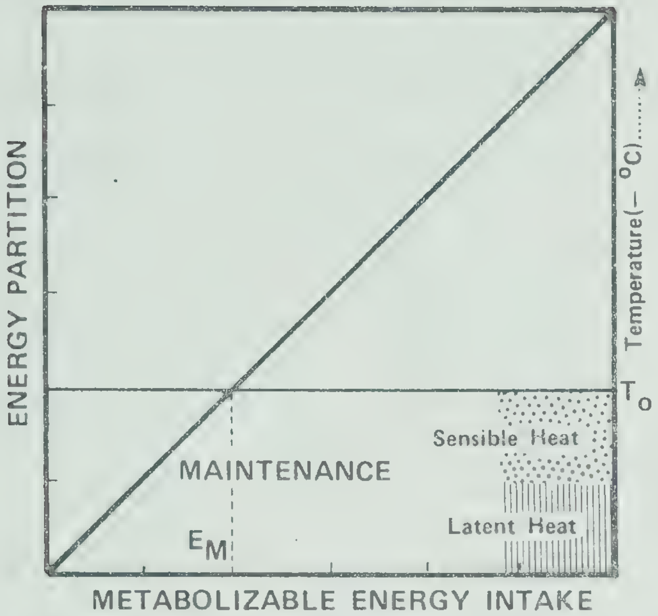

Figure 7. Energy partition diagram showing the lower environmental temperature limit of the zone of thermoneutrality(To)at maintenance feeding level,Em.

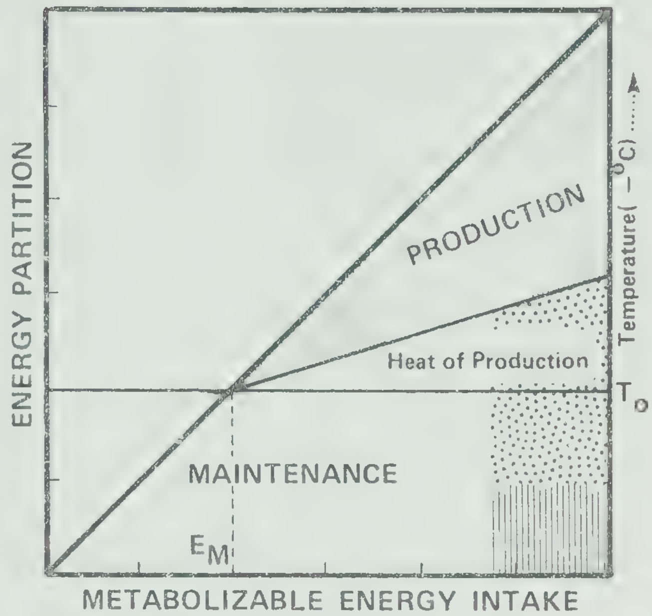

Figure 8. Energy partition diagram indicating the production envelope for new tissues(protein and lipid) when feeding is increased above the maintenance level at, or above environmental temperature To. Note 30% of the feed energy above maintenance appears as the heat of production which must be dissipated from the animal body.

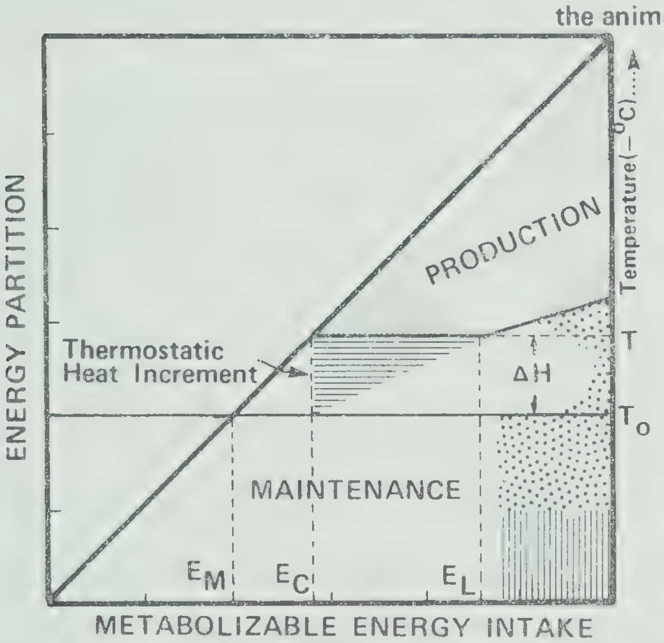

Figure 9 . At T lower than To, the sensible heat increment ΔH , above the sensible heat of maintenance, is required to maintain body temperature. E_L is the lowest feeding level that provides sufficient sensible heat from production to maintain body temperature at ambient temperature T. Ec is the critical feeding level. Between Ec and E_L there is a 1:1 substitution of the sensible heat of production for the thermostatic heat increment.

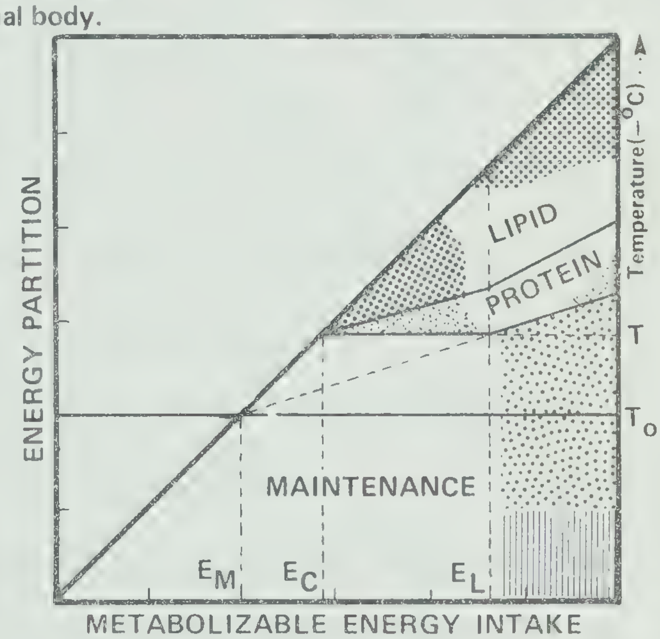

Figure 10. Above the critical feeding level Ec, new tissue produced is 25% protein and 75% lipid.

temperatures at or above T_0, results in the deposition of protein and lipid, and the additional sensible heat increment released by the biochemical reactions associated with this production. The marginal efficiency of energy retention is 70%, as illustrated in Figure 8, where approximately 70% of the incremental energy intake above E_m appears as production (protein and lipid) and 30% as heat. At environmental temperatures above T_0, the heat increment would be dissipated to the surroundings. By corollory, this heat increment can be used to offset body heat losses, enabling the pig to maintain normal body temperatures at environmental temperatures below T_0. This is assuming the heat increment at temperatures below T_0, is lost entirely as sensible heat as was indicated in Figure 2.

In order to maintain body temperature at ambient temperature T, lower than T_0, the maintenance heat output (E_m) must be increased by an amount ΔH, as shown in Figure 9. The intake energy level E_L is of particular significance, since it represents the lowest energy intake that will provide ΔH totally from the sensible heat associated with production. At energy intake level E_c, no production takes place and the increment ΔH must be made up entirely by the pig directly converting intake energy to sensible heat. This reaction should take place with a heat conversion efficiency of 100%, and is referred to in Figure 9 as the thermostatic heat increment. At energy intake levels between E_c and E_L, a portion of ΔH is made up by the sensible heat associated with production, with the remainder provided by the direct conversion of energy intake.

The shape of the production envelope in Figure 9 should be compared to that in Figure 8. At energy intake levels above E_L there is no difference, i.e. the efficiencies of intake energy utilization are the same. Below E_L the envelope in Figure 9 is sharply modified. In particular, decrements in energy intake result in decrements in production at a ratio of 1:1. In other words, reducing energy intake below E_L results in sharp reduction in production.

The energy retained, as shown in Figure 8 and 9, can be partitioned into 25% protein and 75% lipid based on the measurements by Close and Mount (1976[c]) as shown in Table 4. Close and Mount's data suggest the proportion of protein to lipid may increase slightly above these values at low energy intake, but quantitatively, the lipid protein ratio will be of less importance. Figure 10 is a modification of Figure 9 to illustrate the partitioning of energy retained over a range of energy intakes at temperature T lower than T_0. Figure 10 predicts the results illustrated in Table 4, that the proportion of protein to total energy retained is consistent over a range of temperatures.

Clearly, with the addition of calibrated coordinates, Figure 9 and 10 could be used directly as models to relate environmental temperature, energy intake, and energy retained.

Using the results of Close and Mount (1976[b]) for thermoneutral maintenance heat production (420 kJ/d.kg$^{0.75}$), latent heat production (200 kJ/d.kg$^{0.75}$) and marginal efficiency of energy retention(0.7), numbers may be assigned to the energy scales, sensible heat production (Q_s) can be computed, and T_0 may be computed as follows:

TABLE 4. RATIOS OF PROTEIN ENERGY RETAINED TO TOTAL ENERGY RETAINED AT VARIOUS TEMPERATURES AND ME LEVELS AS MEASURED IN GROWING PIGS(FROM CLOSE AND MOUNT,1976).

Approx. ME Level, $kJ/\ d \cdot kg^{0.75}$	Temperature, ^{o}C			
	5	10	15	21
950	0.46	0.41	0.32	0.33
1450	0.26	0.24	0.25	0.24
1700	0.26	0.24	0.25	0.23

$$T_o = T_b - IQ_s W^{0.75} / A \quad \ldots\ldots\ldots\ldots\ldots\ldots 17$$

Taking the insulative value (I) of a pigs surface layer as 0.003 $m^2 d^oC/kJ$ (Fuller and Boyne, 1972), body weight(W) 45 kg, body temperature(T_b) 39^oC, and body surface area, A (m^2) = 0.0754. $W^{0.656}$(Kelley et al, 1973), and substituting in Equation 18:

$$T_o = \left\{ 39^oC - \frac{(0.003\ m^2 d^oC/kJ)(220\ kJ/d.kg^{0.75})(45\ kg)^{.75}}{0.0754\ W^{0.656}} \right\} = 26.1\ ^oC \quad \ldots 18$$

Since T_o values for pigs of 60 and 75 kg can be shown to be approximately the same, 26^oC may be used in a model covering pigs of this weight range.

Starting from T_o at 26^oC, the temperature scale can be calibrated by selecting a temperature below T_o and calculating the incremental sensible heat loss from the pig between 26^oC and the selected temperature (e.g.about 275 kJ/(d.kg$^{0.75}$) at 10^oC). This heat loss increment is added to E_m on the intake energy scale, and the intercept with the 45^o line can be picked off and labelled as the selected temperature. Noting that the heat loss increments are directly proportional to the temperature differential between the selected temperature and 26^oC, a temperature scale may now be plotted.

Figure 11 was constructed using these calculations as a general model relating environmental temperature, energy intake, and energy retention for pigs weighing from 45 to 75 kg. (In the interest of amplifying the scale, energy levels below maintenance have been omitted.) To permit general use of Figure 11, for any temperatures shown, an overlay, partitioning energy retained into 25% protein and 75% lipid has been included in the rear cover of this thesis. A sample problem illustrating the use of Figure 11 and the overlay has been provided in Appendix A1.

This model indicates that low temperature increases heat output. Therefore, to maintain thermoneutral protein and lipid retention rates at low temperature , energy intake must be increased. This could be accomplished in practice by increasing the energy to protein ratio of the existing feed.

Validating the Model

Most of the literature on low temperature effects refers to the influence of temperature on the efficiency of feed utilization. Recognizing that feeding efficiency can be readily calculated from the model at any temperature and feeding level, a comparison of predictive results from the model with recorded experimental results becomes a straightforward matter.

The locus of points E_C and E_L from Figure 10, for ambient temperatures $26^{o}C$ down to $5^{o}C$, are shown as two straight lines in

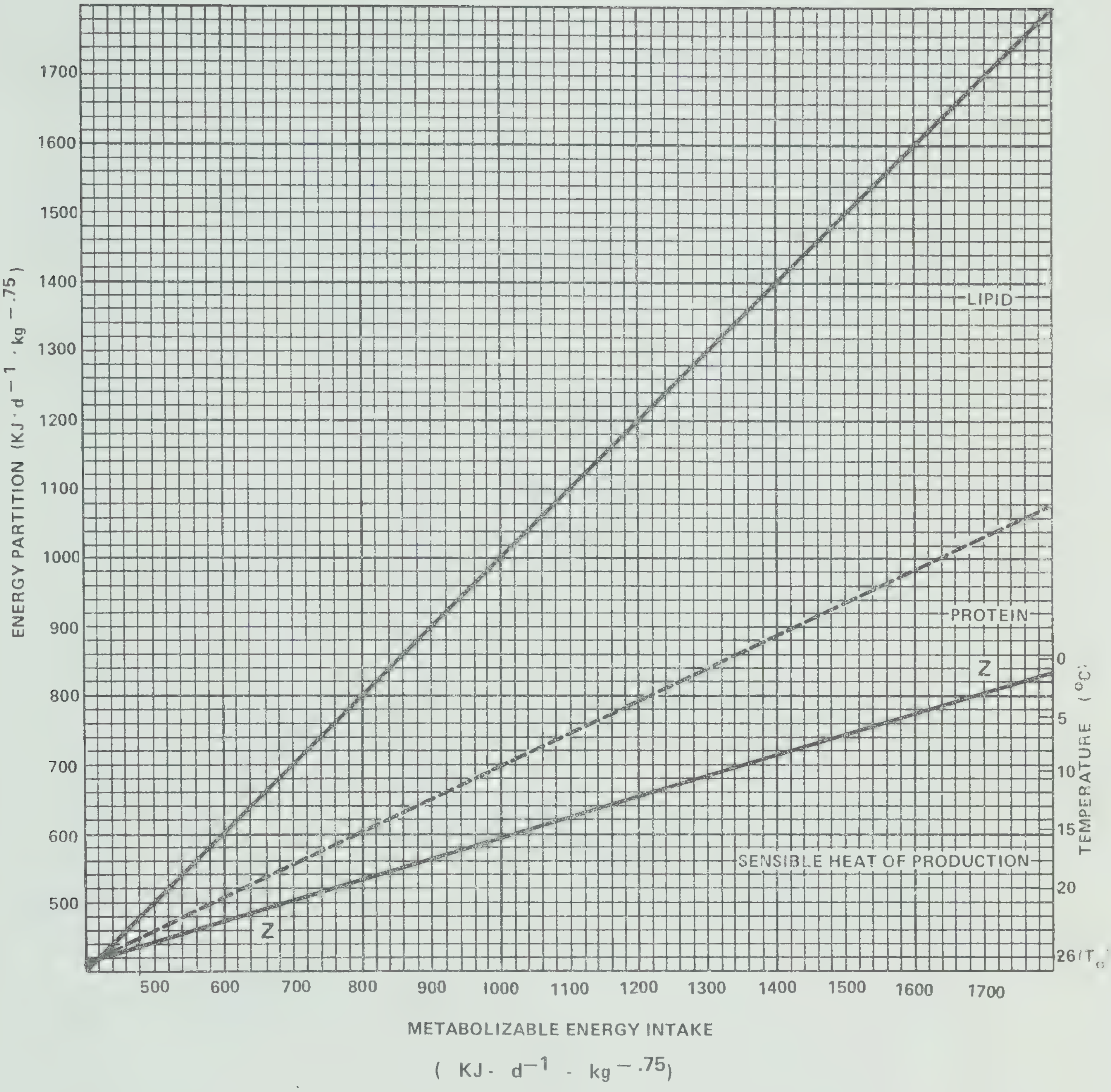

Figure 11. The above diagram can be used with acetate overlay(rear cover) to predict lipid and protein retention in growing pigs(45 to 75 kg) over the range of temperatures shown.

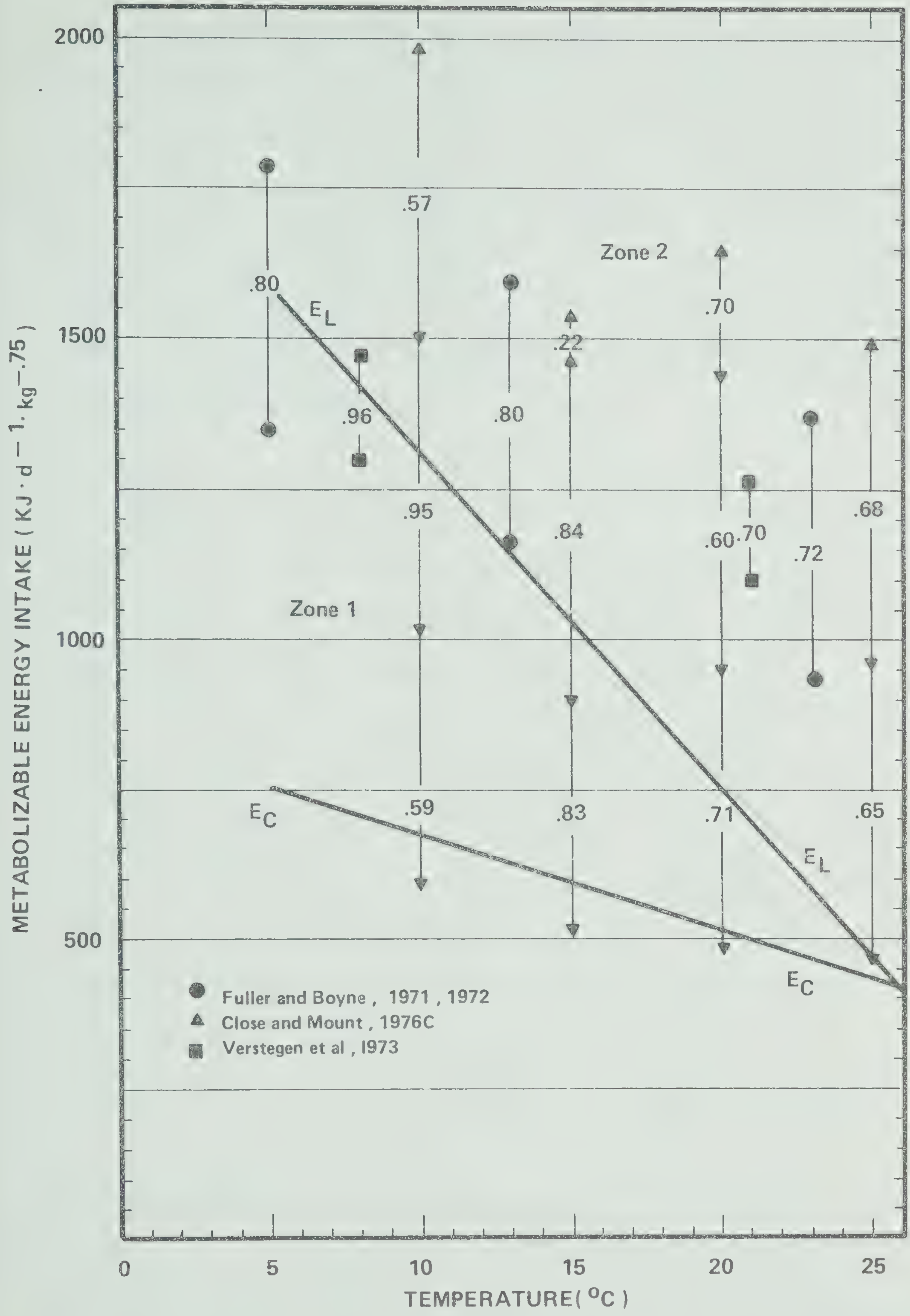

Figure 12. Marginal efficiencies of energy retention as predicted by the model and as computed from several sources in the literature. (Zone 1 predicted 100 %; Zone 2 predicted 70 %.)

Figure 12. Recalling from earlier discussions that increments in ME intake between E_C and E_L are retained as energy in the body at a ratio of 1:1, predicted marginal efficiency of energy retention between the E_C and E_L lines should be 100%. Reference to Figure 10 also will establish that ME increments in the region above line E_L in Figure 12 are retained in the body with an efficiency of 70%. Pigs are normally maintained in this zone and are producing heat beyond their thermostatic requirement.

Superimposed on Figure 12 are marginal efficiencies of energy retention from three studies reported in the literature (Fuller and Boyne,1971,1972; Close and Mount,1976c; Verstegen et al,1973), for pigs at various temperatures, computed over the increments in ME levels used (see sample calculation in Appendix A2). Temperatures shown in Figure 12 are as quoted from each source and no attempt has been made to correct for varying conditions such as air movement and floor conditions (i.e. effective temperature). For example, air movement levels were above normal confinement values (about 25 cm/s;Hahn,1976) in the experiment of Fuller and Boyne (1971, 1972), and probably temperature could be scaled down from 23°, 13°, and 5°C to about 20°, 10°, and 1°C, to represent effective temperature at 25 cm/s air movement.

The marginal efficiency zones predicted from Figure 11 compared quite well with the reported marginal efficiency values shown in Figure 12. Therefore, the model warranted testing in a practical feeding trial.

SECTION E

FEEDING TRIAL: PROTEIN DEPOSITION, WEIGHT GAINS

Introduction

The current economic structure of the pork industry emphasizes the production of lean pigs. In addition, the conversion of feed energy, in excess of maintenance requirements into fat, represents an energetic cost per unit gain over three times that for lean tissue weight gain (Whittemore and Elsley, 1976). Therefore, methods of ration formulation and feeding which can achieve leaner growth are desirable.

Linear models partitioning energy intake into protein and lipid energy have been developed for sheep (Black, 1974) and pigs (Fowler, 1978). The previous section extended the Fowler model for pigs to include the effects of low temperature. While the energy retention properties of the model compared quite well with the results of several reported experiments by other researchers, the partitioning of energy retained by fixed proportions into protein and lipid was based on one study by Close and Mount (1976). Since not all studies have reported reduced protein retention rates in pigs exposed to low temperatures (Verstegen et al, 1973), a feeding trial was undertaken to test the protein deposition aspect of the model.

Experiments to determine the influence of low temperature and feeding level on swine performance have been designed several ways. Perhaps the

simplest is to expose a given group of pigs to only one plane of nutrition and one temperature regime in a given experiment (e.g. Verstegen et al, 1973). In other designs researchers have exposed pigs to one temperature regime but have changed the plane of nutrition during the study period (e.g. Close et al, 1971). Still other designs have exposed pigs to a constant plane of nutrition but with consecutive temperatures in a given experiment (e.g. Holmes and Mount,1967). Although the best approach is not clear, the latter study (Holmes and Mount,1967) contains a forthright statement regarding the limitations of the consecutive temperature design:

> " In Experiments 1 and 5 the rate of gain immediately following the change from 20 to 9 C was less than that occurring before and after (see Figure 4). Within the time limits of the experiment it is doubtful whether steady rates had become established following the change of environmental conditions,....A comparison of gain rates at the different ambient temperatures is therefore not meaningful."

This admission appears serious and later researchers were quick to point out the shortcomings of this design (Verstegen et al,1973). However a close examination of Figure 4 in Holmes and Mount(1967), suggests that the design used did indeed establish steady rates of gain but not until about 5 days after the temperature change.

Since Holmes and Mount (1967) did not measure protein retention rates, the adaption of their consecutive temperature design to test the protein deposition aspects of the model was considered worthwhile. This afforded the opportunity of probing one step further, that is, to quantitatively distinguish between the chronic effects of low temperature and the acute effects induced by temperature change. Such additional information would be valuable and worthwhile as a secondary objective to a feeding trial.

Protein retention rates are measured during feeding trials on pigs, by either the slaughter technique or the nitrogen balance method. Some experiments have used both methods (Fuller and Boyne, 1971, 1972; Nielson, 1970). The slaughter technique is the more accurate of the two methods and is particularly useful when the entire growth of the animal is to be considered as one study period. However, the number of animals required when using this method could become prohibitive where numerous consecutive short study periods are desired. Fuller and Boyne have shown that although the nitrogen balance method tends to overestimate protein deposition rates compared to the slaughter technique, results are quite satisfactory where response to treatments is of interest. Therefore, the nitrogen balance technique was used to estimate protein deposition rates for pigs exposed consecutively to two temperature regimes.

Methods

Experimental Design.

A double reversal designed experiment with four periods (three changeovers) was used to determine the effectsof low temperature on rates of protein deposition and weight gains in growing-finishing pigs (45-80 kg body weight). Two groups of eight individually-caged pigs (female, Yorkshire X) were exposed alternately for 15-day periods to 6^{o}C (Room 1) and 21^{o}C (Room 2) as shown in Table 5. The last 10 days within each period (divided into two equal subperiods), were measured to obtain the steady-state or chronic response of growth to energy intake and temperature. Results of the acute effects of the three abrupt temperature changeovers on body weight, assumed to be included within the first five days of each period (Subperiod 1), have been reported in the next chapter.

Animals

Sixteen Yorkshire X gilts were obtained from the University of Alberta Swine Research Unit. The pigs varied in weight between 25 and 40 kg on the day of delivery (May 23/78) to the experimental facilities at the Department of Agricultural Engineering, Ellerslie Research Station. The pigs were divided randomly into two groups and the mean weights of each group were computed to ensure they were similar (Group 1, 31.9 kg; Group 2, 31.0 kg). Group 1 pigs were numbered 11 to 18 and were placed in Room 1; Group 2 pigs were numbered 21 to 28 and were placed in Room 2. Feeding treatments were imposed immediately with Pigs 11 to 14 and 21 to

TABLE 5. EXPERIMENTAL DESIGN SHOWING THE ORDER IN WHICH GROUP 1 AND 2 PIGS WERE EXPOSED TO TEMPERATURE TREATMENTS.

	Group 1		Group 2	
Period	Restricted (Pigs #11-14)	Ad Libitum (Pigs #15-18)	Restricted (Pigs #21-24)	Ad Libitum (Pigs #25-28)
1	$6^{o}C$ *		$21^{o}C$ **	
2	$21^{o}C$		$6^{o}C$	
3	$6^{o}C$		$21^{o}C$	
4	$21^{o}C$		$6^{o}C$	

* Room 1 temperature $6^{o}C$
** Room 2 temperature $21^{o}C$

24 receiving restricted amounts of feed, as detailed below, and Pigs 15 to 18 and 25 to 28 had ad Libitum access to feed. Both rooms were maintained at 21±2^{o}C (ambient temperatures) for the first 23 days, until June 15, while the pigs adjusted to the experimental routine. During this time, referred to as the "Preliminary Adjustment Program", the pigs became accustomed to the procedure of being moved from one room to the other. The experimental program was commenced at 16:00 h on June 15, and ended exactly 60 days later at 16:00 h, August 14. Group 1 started the experimental program in Room 1(cold) and finished in Room 2(warm). Groups were changed to the opposite rooms at the end of each period, that is, on June 30, July 15, and July 30, at 16:00 h.

Individual rectangular cages (1.52 X 0.42 m) with expanded metal walls, placed directly on sloping (3% to the rear of the pigs) floors, were used to house pigs in both rooms (Figure 13). Sixteen cages were placed in each room allowing a vacant cage between each pig. Incandescent lighting was provided 24 h/d.

Feeding

From the time of arrival at the experimental facility, pigs were fed increasing amounts of feed, adjusted every other day, according to their metabolic body weight ($W^{0.75}$, Kleiber, 1961). Half the pigs in each group were offered pelleted ration ad Libitum, while the other half were restricted to 100 g of feed (as fed basis) per day per unit metabolic body weight, i.e.:

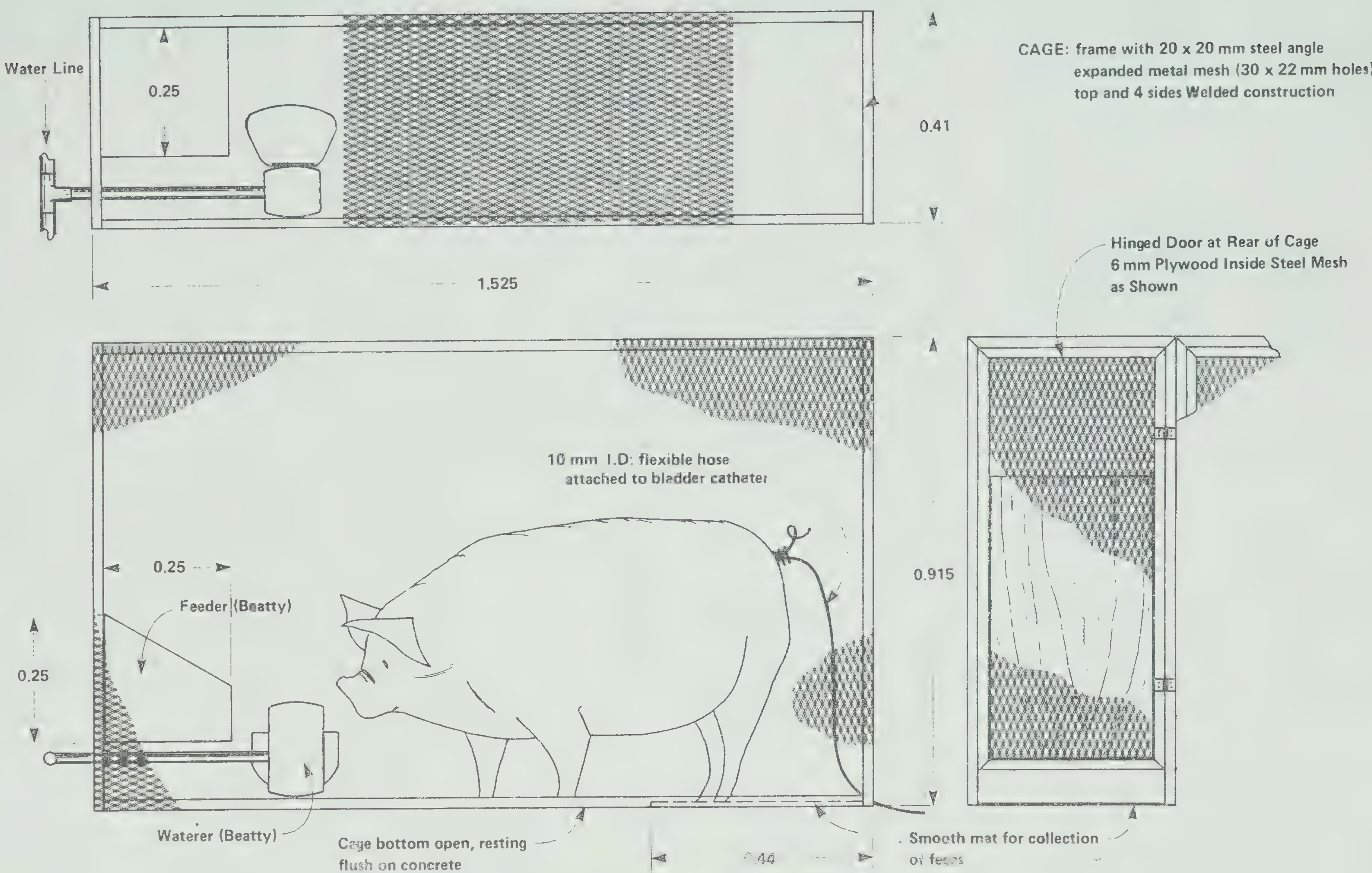

Figure 13. Individual cages for pigs(dimensions in metres).

$$\text{Daily feed, Restricted Pigs} = (100\text{ g})\ (W^{0.75}\ (\text{kg})) \quad ..19$$

Feeding tables for restricted-fed pigs are listed in Appendix A3. Feed was offered at 05:00 and 16:00 h each day. Spilled feed was returned to the feed bowl and feed not eaten at the end of each subperiod was weighed, and the amount deducted from that given during the subperiod.

Ration formulations, based mainly on barley and soybean meal, are shown in Table 6. Daily feed aliquots were composited for each subperiod, ground, and analysed for dry matter,total nitrogen, and total heat of combustion. Pigs were changed from Growing to Finishing ration at 55 kg body weight as normally done under commercial conditions.

Water was provided ad Libitum in individual water bowls.

Collection of Feces and Urine

During the preliminary adjustment program, fecal matter in and about the cages was scraped up daily; pens were not washed down. Therefore, a small residual of fecal matter accumulated in cracks and corners of the cages. In order that this residuel of feces remain at a constant level, cages were scraped clean in the usual manner only at the commencement of the experimental program.

TABLE 6. RATION FORMULATION.

Constituent	Growing Phase (pigs 35-55 kg)	Finishing Phase (pigs 55-85 kg)
Barley	500	845
Wheat	315	0
Soybean Meal	150	120
Salt	5	5
Calcium Phosphate	10	10
Calcium Carbonate	10	10
Vitamin-Mineral Premix	10	10
Total	1000	1000

Cages usually were inspected each hour between the hours 05:00 and 23:00 each day and feces from each pig were removed from the cage floor and stored in plastic pails. Most of the pigs kept their pens very clean but a few animals were messy and would lie or sit in the feces. A short test was conducted in which 453 g of wet feces from a messy pig was collected shortly after defecation, and weighed. The sample was then returned to the floor under the pig. At the end of 30 minutes the pig had walked, sat and lain in the feces sample. The floor was then scraped up and the sample reweighed at 435 g (4% loss). The actual loss of feces during any one period should not exceed this since such losses do not accumulate.

At the end of each five-day subperiod, the accumulated feces from each pig were weighed, mixed, and a fraction (usually 25% by weight) was dried (60^{o}C for 24 h), ground, and analysed for total nitrogen, dry matter, and total combustible energy (TCE). See below for analytical procedures.

Bladder catheters (Bardco, Foley type) were implanted in all pigs (catheter implantation procedure described in Appendix A4) to transfer urine via 2 m (10 mm I.D.) flexible tubing to collecting bottles containing sufficient HCl (100 to 200 ml of 0.1 N) to maintain urine pH below 5. Composite subperiod samples for each pig (10% aliquots) were retained (stored at 5^{o}C) and analysed for total nitrogen.

Liveweight Measurement and Changeovers.

Pigs were weighed individually every other day, to the nearest 250 g, on hog scales located in each room. Catheter transfer tubes were coiled and tied to the tail of each pig (catheter assembly weight about 250 g). Any fecal droppings passed during weighing were returned to the appropriate pail. After weighing tubes were uncoiled and returned to the collection vessels with no loss of urine.

Occasionally, the weighing could not be made, however, the bi-daily schedule of feed adjustment was maintained by linear extrapolation of the weight records for each pig. This procedure also was used on the fourteenth day of each period since the pigs were weighed out on day 15 at the changeover.

During changeovers, at 16:00 h on day 15 of each period, pigs in Room 1 were moved to Room 2 and vice-versa. Catheter assemblies were coiled as explained above and pigs were moved individually between rooms (about 75 m) in a small wagon. This operation was completed in about 45 min.

Analytical Methods

Total nitrogen of feed, feces and urine was determined using the official "Improved Kjeldahl Method" as per Section 2.049, AOAC (1975). Crude protein was calculated as Total Nitrogen multiplied by 6.25 as per Section 2.016, AOAC (1975).

One gram samples of feed and feces for dry matter determination were ground and dried to constant weight at 110^{o}C (about 4 hours).

Total combustible energy content of 1 g samples of feed and feces was determined using a Parr Adiabatic Bomb Calorimeter (Parr Instrument Co., Moline, Ill, U.S.A.).

Measurement of Protein Retention

The nitrogen balance technique was used to estimate protein deposition rates for each pig during each subperiod (5 days) as expressed in the following equation:

$$\text{Protein Retention} = 6.25(\text{ N Feed} - \text{N Feces} - \text{N Urine }) \text{.... } 20$$

Nitrogen balance measurements were each five-day subperiod.

Energy Intake

Metabolizable energy intake(ME) was computed for each subperiod as follows:

$$\text{ME} = \text{TCE Feed} - \text{TCE Feces} - \text{TCE Urine } \text{......... } 21$$

Urine energy was calculated by assuming that 45 kJ was lost with each gram of urine nitrogen (Whittemore and Elsley, 1976). No allowance was made for combustible gases.

Physical Environment

Average subperiod temperatures and relative humidities were computed from recording hygro-thermographs (Belfort Instr. Co.) placed in a vacant cage, 30 cm above the floor in each room. Instruments were calibrated with a mercury thermometer. Values at 06:00, 12:00, 18:00, and 24:00 h each day of the subperiod were used in calculating subperiod mean temperature and relative humidity (i.e. 20 readings).

Air speeds within the zone of occupancy were measured by a hand-held anemometer that uses a hot-wire probe (Sierra Instruments,California).

Statistical Analysis

The statistical model used to analyse the variation in measurements is shown in Table 7. Period X Group variation was used to determine the significance of temperature treatments.

Analysis of variance and treatment means were calculated using Agriculture Canada Statistical Library Programs S022 and S199, respectively. Missing data were handled using the covariance method.

TABLE 7. STATISTICAL MODEL USED TO ANALYSE TREATMENT EFFECTS.

Source	Degrees of Freedom	
Groups (G)	1[a]	1[b]
Feed (F)	1	1
Groups x Feed	1	1
Hogs/Groups x Feed	12	12
Periods (P)	3	2
Periods x Groups (Temperature)	3	2
Periods x Feed	3	2
Periods x Groups x Feed	3	2
Periods x Hogs/Groups x Feed	36	24
Total	63	47

a, degrees of freedom for Periods.
b, degrees of freedom for Changeovers.

Results

Climatic Environment

Average subperiod temperatures and relative humidities for Room 1 and Room 2 are shown in Table 8. Comparing the mean temperatures for the entire experiment,the two room were 15 Centigrade units apart (Room 1, 6.2^{o}C, std. dev. 2.4; Room 2, 21.3^{o}C, std. dev. 2.8). Relative humidity in Room 1 was practically constant at 100 % while the average for Room 2 was 59% (std. dev. 4.0%). Mechanical problems with the Room 1 refridgeration unit caused slightly warmer temperatures than desired during Periods 1 and 2. The temperature difference between rooms however remained fairly constant. Air movement was found to average 25±15 cm/s at any given location within the cages.

The moisture condition of the concrete floor beneath the pigs varied with each pig, ranging from dry to continually wet. However for most pigs the floor was usually dry, even in Room 1 where the relative humidity was high.

Journal of Animals

The experiment was designed to contain 192 observations(16 pigs X 12 subperiods), of which 123 were obtained. The balance were missed for these reasons: 12 observations were missed at the beginning of the experiment because of problems with bladder catheter implantation. Most catheters were implanted during Subperiod 2 of Period 1 and nitrogen

TABLE 8. AVERAGE AIR TEMPERATURES (^{o}C) AND RELATIVE HUMIDITIES (% R H) AT PIG HEIGHT IN ROOM 1 AND ROOM 2 BY PERIOD AND SUBPERIOD.

Period	Subperiod	Room 1			Room 2			
		^{o}C	std. dev.	% RH	^{o}C	std. dev.	% RH	std.dev.
1	1	7.9	2.56	>99	21.9	1.72	52	5.9
	2	6.4	1.67	>99	22.1	2.33	57	4.6
	3	8.8	2.28	>99	23.9	2.17	56	7.4
2	1	6.4	1.89	>99	23.0	2.17	56	8.0
	2	5.8	1.28	>99	18.9	2.28	60	6.4
	3	7.7	0.89	>99	19.8	2.28	67	8.7
3	1	5.2	1.72	>99	19.9	2.78	60	5.4
	2	6.0	1.72	>99	21.4	2.17	59	4.9
	3	4.9	1.00	>99	21.6	2.67	62	10.5
4	1	4.4	1.11	>99	19.2	2.56	56	5.5
	2	5.4	1.17	>99	22.4	1.89	56	8.1
	3	5.7	1.44	>99	20.9	3.17	63	6.5
		Experimental Mean						
		6.2	1.33	>99	21.3	1.56	59	4.0

balances for those pigs were commenced at 16:00 h on the day of implantation. Rather than discarding this nitrogen balance data gathered during the remainder of Subperiod 2, these data were added to the five days nitrogen balance data obtained in Subperiod 3. The number of days in Subperiod 2 which were added to Subperiod 3 are shown in parentheses in the feed table at the beginning of Appendix B1. All other feed values given are based on five days.

Animal health problems were the cause of the remaining missing observations. Some of the health problems arose because of the experimental manipulations. Included in Appendix A5, is a summary journal for each pig. Rectal prolapses were responsible for the loss of several observations. Shortly after the experiment commenced, the initial Pig 14 had to be discarded along with all the results collected for her. She was replaced immediately and records for Pig 14 begin at Period 2. Toward the end of Period 1, Pig 25 had a rectal prolapse; she was discarded and not replaced. Pig 13 prolapsed during the middle of Period 3 but she recovered after a time and was retained in the experiment. Pig 21 prolapsed with 3 days left in the experiment. During Periods 2 , 3, and 4, catheters were removed whenever the rectum showed signs of protrusion. Minor health problems were responsible for the rest of the missing data. Four observations were lost due to plugged catheters, two due to hemorrhaging in the urinary tract, and one due to diarrhea.

In this experiment, Subperiods 2 and 3 were assumed to contain the steady-state effects of temperature treatments. When results from

Subperiods 2 and 3 were pooled, entries existed for 59 of the possible 64 Period X Pig cells (92%). Therefore, values used in the analysis of variance for steady-state variables are pooled values from Subperiods 2 and 3. Further comments pertaining to the method of analysis of individual variables are included in their respective sections.

In view of the health problems discussed above, only effects statistically significant at the 99% level of probability (hereafter denoted **) have been reported.

Feed and Energy Intake

The average daily feed consumption by the Group 1 and Group 2 ad Libitum-fed pigs (111.5 g/($kg^{0.75}$)) was about 11% (**) more than that consumed by the Group 1 and Group 2 restricted-fed pigs (98.5 g/($d.kg^{0.75}$)), (see Table 9 for summary, Appendix B1 for raw data, and Appendix C1 for Analysis of Variance (AOV)). The experimental mean total combustible energies of the grower and finisher rations were very similar (15.8 MJ/kg, std. dev. 0.23 vs 15.9 MJ/kg, std. dev. 0.15, respectively) as were the average protein concentrations (16.2%, std. dev. 0.72 vs 15.4%, std. dev. 2.11, respectively).

Mean ME intakes for each treatment combination are shown in Table 9. The mean ME intake of the restricted pigs was on average, about 90% (**) of the ad Libitum fed pigs (raw data in Appendix B3 and AOV in Appendix C2).

TABLE 9. EXPERIMENTAL RESULTS FOR EACH TREATMENT COMBINATION(MEAN OF 4 (3) PIGS): A, FEED INTAKE,(AS FED BASIS), g/(d·kg·75); B, METABOLIZABLE ENERGY INTAKE, kJ/d·kg·75; C, AVERAGE DAILY GAIN,g /d; D, MEAN BODY WEIGHT, kg;E, PROTEIN DEPOSITION RATE,kJ/d·kg·75;F, PROTEIN GAIN/TOTAL GAIN, g /g .

		Group 1		Group 2		
Period	Code	Restricted	Ad Libitum	Restricted	Ad Libitum	Period Mean
1	A	99.3	128.0	101.3	115.0	111.7
	B	1177	1408	1239	1386	1311
	C	391	654	782	741	659
	D	45.2	49.5	53.2	51.0	50.2
	E	113 (3)	131	84	135	116[a]
	F	0.216	0.157	0.093	0.155	0.151[a]
2	A	97.8	116.5	99.0	100.7	103.7
	B	1202	1404	1159	1168	1238
	C	742	844	489	538	661
	D	56.2	62.0	59.1	57.1	58.7
	E	168	192	110	86 (3)	142[a]
	F	0.201	0.229	0.207	0.145	0.199[a]
3	A	99.3	103.3	96.8	99.3	99.7
	B	1178	1218	1193	1225	1204
	C	406	485	747	914	646
	D	61.5	69.5	69.7	63.4	66.6
	E	143 (3)	133	164	188 (3)	156[b]
	F	0.329	0.306	0.227	0.198	0.262[b]
4	A	96.8	107.5	98.8	119.3	104.7
	B	1201	1309	1181	1409	1266
	C	650	917	497	662	683
	D	70.6	81.9	76.0	73.8 (3)	75.7
	E	126	131	118	144	129[a]
	F	0.220	0.179	0.255	0.236	0.220[b]
Feed X Groups	A	98.1[a]	113.8[b]	98.9[a]	109.1[b]	
	B	1191[a]	1335[b]	1193[a]	1304[b]	
	C	568[a]	741[b]	629[a]	716[b]	
	D	59.1	65.7	64.5	60.5	
	E	139	147	119	138	
	F	0.237	0.210	0.196	0.181	
Periods X Groups (Temperature)			$6^{\circ}C$		$21^{\circ}C$	
	A	99.1[a]	112.8[b]	98.2[a]	109.6[c]	
	B	1174[a]	1301[b]	1209[a]	1331[b]	
	C	446[a]	585[b]	730	854	
	D	60.5	62.5	62.4	64.6	
	E	121	124	136	162	
	F	0.252	0.211	0.186	0.189	
Mean of Ad Lib And Restricted	C	516[a]		792[b]		
	D	61.5		63.5		
	E	123[a]		149[b]		
	F	0.232[a]		0.187[b]		

a,b,c Means in the same row or column, with different letters are significantly different(**).

Liveweight Gains and Mean Period Weights

The experimental mean daily gain for all pigs, based on least-squares linear regression on the liveweight measurements for Subperiods 2 and 3, was 663 g (liveweight records are included in Appendix B4). Mean daily gains for each treatment combination are shown in Table 9. The chronic effect of low temperature($6^{o}C$) was to diminish average daily gain by 18.4 g/d.^{o}C or 2.3 %/^{o}C below the rate of 792 g/d weight gain measured at $21^{o}C$ (Raw data in Appendix B5 and AOV in Appendix C3). The average daily gain based on the difference over 60 days of the mean starting weight (44.6 kg) and finishing weight (81.5 kg), was 607 g. The effects of temperature change on liveweight, as measured over the first five days of each period, are reported in the next chapter.

Mean period liveweights, for each pig, were computed from the same values used in computing the regression coefficients of daily weight gain, and mean period liveweights are shown in Table 9 (Raw data is shown in Appendix B6). Metabolic body weights, used to express other results such as protein deposition rates, were computed from these values to the 0.75 power.

Increasing feed intake increased daily gain by 10.3 g/d per extra gram of feed over the restricted feeding rate of 100 (g/d.$kg^{0.75}$).

Protein Retention.

Protein retention was analysed statistically using the mean of Subperiods 1 to 3 and also using the mean of Subperiods 2 and 3 only (raw data in Appendix B7 and AOV's included in Appendix C4 and C5). Since the subperiods included made no difference to the statistical outcome, protein retention values for each period are based on the mean of all data.

Although protein deposition rates averaged 14% higher for the ad Libitum fed pigs than the restricted pigs, feed level and other feed interactions did not reach statistical significance. Based on the average feed consumption, low temperature ($6^{o}C$) was found to diminish protein retention at a rate of 1.73 kJ/(d.kg .^{o}C), or 1.2%/^{o}C(**), below the rate measured at $21^{o}C$ (149 kJ/(d.kg$^{0.75}$)) (AOV shown in Appendix C5). Protein retention rates for each treatment combination are summarized in Table 9.

The computed ratio of protein gain to total weight gain (P/G), was higher at $6^{o}C$ (0.232) than at $21^{o}C$(0.187), indicating leaner growth (**) at low temperatures (raw data in Appendix B8 and AOV shown in Appendix C6). P/G ratios for each treatment combination are shown in Table 9.

Protein accretion rates for Period 1, 2, and 4, were not significantly different (Student-Neuman Kuels test, $P<0.01$) and averaged 129 kJ/(d.kg$^{0.75}$) while Period 3 rate was higher at 156 kJ/(d.kg$^{0.75}$) when the pigs averaged 67 kg body weight. The effect of

periods on the P/G ratio was similar to that for protein retention. The P/G ratio for Period 3 (0.262) was higher than the remaining periods which averaged 0.190.

Discussion

Without the necessary heat production to maintain body temperature, the pig would become hypothermic and die eventually. In order to meet the extra heat demands at low temperature, feed energy that otherwise may be incorporated into new tissue must be oxidized instead to produce heat. Therefore prolonged exposure of the pig to low temperature will result in a reduction in growth rate, or more specifically, diminished rates of protein and lipid retention.

In Section D, these concepts were developed into a 3-dimensional model capable of predicting production of protein and lipid over a range of temperatures and energy intake levels. Since lean tissue production is a fundamental concern in the development of effective methods of feeding pigs, further tests were conducted to establish the protein deposition aspect of the model.

The protein deposition response of the model to increasing energy intake was supported substantially by the experimental results. Reference to the model using the energy intake levels shown in Table 9, predicts a 10% increase in ME intake to result in a protein retention rate increase

of about 20% at 6^{o} and $21^{o}C$. The actual average increase in protein retention rate for the ad Libitum fed pigs, as compared to the restricted fed pigs, was slightly less at 14%. However, because of the animal variability encountered, this increase in rate of protein retention was not significant. Therefore, in comparing temperature effects, feed levels have been pooled simply by averaging the energy intake values for the restricted and ad Libitum fed pigs (1238 at $6^{o}C$; 1270 $kJ/(d.kg^{0.75})$ at $21^{o}C$).

Daily increments in mass of lean tissue, fat, bone, and gutfill, in the growing pig, all constitute what is called liveweight. In the production of slaughter pigs, performance is most often associated with liveweight gains. Also of importance is the need to produce pigs with a minimum of excess body fat. Table 10 compares several important performance parameters for growing pigs exposed to 6^{o} and $21^{o}C$, as predicted by the model and as determined from this study.

Protein, in Table 10, has been compared directly by assuming the energy content of protein to be 23.5 kJ/g (A.R.C., 1967). The efficiency of utilization of ME for the production of protein is expressed in the ratio ME/Protein Retention. Both parameters can be compared directly and agree very closely (2%). The remaining three comparisons, Daily Gain, Protein Retention/Daily Gain, and Lipid Retention, have been made indirectly by assuming the mean energy content of tissues retained by a 60 kg pig to be 19.4 kJ/g (Holmes and Close, 1977) and by allowing 10% of average daily gain for ash and gutfill (Verstegen et al, 1973).

TABLE 10. COMPARISON OF FEEDING TRIAL RESULTS WITH MODEL PREDICTED RESULTS(FROM SECTION D).

Temp, °C	ME Intake, $kJ/d \cdot kg^{0.75}$	Variable	Model	Feeding Trial	$\{\frac{Trial}{Model}\}^{\dagger}$
6	1238	Protein Retention, $kJ/d \cdot kg^{0.75}$	125*	123	0.98
		ME/Protein Retention	9.9	10.1	1.02
		Daily Gain, $g/kg^{0.75}$	24.0√	23.0	0.96
		Protein Retention/Daily Gain	.222√	.232	1.05
		Lipid Retention	355*	279√	0.79
21	1270	Protein Retention, $kJ/d \cdot kg^{0.75}$	150*	149	0.99
		ME/Protein Retention	8.5	8.6	1.01
		Daily Gain, $g/kg^{0.75}$	34.7√	35.4	1.02
		Protein Retention/Daily Gain	.184√	.187	1.02
		Lipid Retention	455*	469√	1.03

* Values in $kJ/d \cdot kg^{0.75}$ (±5) as read from Figure 11.
√ Estimated values, see text.
† ratio of feeding trial value to model predicted value.

Using these values, the model predictions of protein and lipid energy gain can be converted into an equivalent daily gain in body weight as follows:

$$(\text{Gain})\ (0.9) = (\text{Energy Retained})/(19.4\ \text{kJ/g}) \quad \ldots\ldots\ 22$$

The predicted daily weight gains at 6° and $21^{\circ}C$ are within 4% of those values determined from this study, both indicating exposure to the low temperature reduced daily gain by about 33%. By converting protein energy to mass, Protein/ Daily Gain ratios predicted are seen to be within 5% of those measured. Both indicate low temperature ($6^{\circ}C$) increased the proportion of protein in daily gain by about 20%.

The last item to be compared in Table 10, Lipid Retention, has been estimated from the results of this study simply by rearranging Equation 23 as follows:

$$\text{Lipid Retention} = (\text{Gain})(0.9)(19.4\ \text{kJ/g}) - (\text{Protein Retention}) \quad ..23$$

Although these lipid estimates are necessarily more speculative than the other protein related parameters, they nevertheless do come surprisingly close (+3% and -21% deviations at 21° and $6^{\circ}C$, respectively) to those predicted by the model. Since fat contributes to body weight, the 21% deviation may seem at odds with the good agreement (within 4%) already

noted for daily weight gain. However, the energy value per gram of tissue is much higher for fat than for a unit weight gain.

Therefore, from the results of this study, the model has proven capable of predicting the protein deposition response of growing pigs exposed to low temperature. Further testing will be needed to establish confidence in the model beyond the limits tested by this feeding trial, especially for pigs substantially different from 50 kg and exposed to temperatures other than were used in the present trial.

Feeding trials will be required to establish confidence in the lipid deposition aspect of the model, however, indirect estimates suggested predicted lipid deposition rates may be within 21% of actual rates, at the energy intake levels used.

The introduction to this section referred to an earlier study by Holmes and Mount(1967) using a consecutive temperature design. They observed unusually low rates of gain in growing pigs during the first five days following a temperature change from 20 to 9^{o}C and suggested that this transient effect " could be due to the net result of changes in body water and fecal output ". While this section has focussed on the steady-state response of pig growth after five days at low temperature, the next section examines the pigs weight response during Subperiod 1 in order to quantify possible transient effects. Some awareness of temporary effects is needed or the usefulness of this, or any, model may be brought into question.

SECTION F

FEEDING TRIAL: WEIGHT AND DIGESTIVE RESPONSE TO ACUTE COLD

Introduction

Meat producing animals exposed to low temperature may be forced to convert productive feed energy into heat in order that body temperature be maintained. As losses of heat energy cannot be regained, some weight is permanently lost, unless the efficiency of tissue production after cessation of cold stress can be shown to increase. So far there is no evidence of this.

The above remarks are from an energy balance viewpoint. However, fieldwork and research to determine the effects of low temperature on livestock performance often is based on liveweight data as this is what interests producers. Although such work is useful, research has indicated that the use of liveweight data when studying low temperature effects may lead to false conclusions. Beyond the permanent tissue losses discussed above, studies by Young (1975) and Degen and Young (1979) indicate there are also temporary body weight losses associated with the animals physiological adaptation to a new temperature regime. These losses are distinct from energy balance considerations and may involve, for example, body water content (Young, 1975). When cold stress is removed, the animal regains it's previous physiological state, including the body weight that was lost temporarily.

Possibly these temperature-induced temporary weight changes are actually the net result of several physiological responses to stressful situations(Holmes and Mount,1967). For example, research on cold-exposed sheep receiving a constant amount of feed has shown a reduced retention time of digesta at low temperature, together with a reduced digestibility of feed (Kennedy et al, 1976). These findings indicate a change in gutfill which would necessarily affect liveweight.

The results of the feeding trial, described in Section E, provide an opportunity to further examine the magnitude of temporary weight changes in cold-exposed pigs, and the reduction, if any, in digestibility of feed nutrients during cold exposure, in order to determine whether any correlation exists between the two responses.

Methods

As described in Section E, a feeding trial was conducted to measure the steady-state gains in body weight and protein during exposure of growing-finishing pigs to 6^{o} and $21^{o}C$. For this purpose, values measured during the last 10 days of each 15-day period were analysed and presented. In view of the questions posed in the introductory part of this Section concerning temperature-induced temporary body weight changes, a further investigation of the results of the feeding trial, paying particular attention to weight gains or losses during the five days

immediately after the temperature change (Subperiod 1) would be appropriate.

In addition to providing detail on experimental and cage design, reference to Section E will provide a description of the methods used for feeding, weighing, calculating the average daily weight gain, and collecting the feces and urine. Additional data from the feeding trial were analysed as follows:

(a) Digestibilities of energy, nitrogen, and dry matter were calculated according to the equation:

$$\% \text{ Digestibility} = ((\text{Intake} - \text{Fecal Loss})/\text{Intake})(100) \quad \ldots\ldots 23$$

Data from Subperiods 2 and 3 were pooled for statistical analysis to determine whether temperature or feeding level had any effect on digestibility of energy, nitrogen, or dry matter.

(b) From bodyweight records, estimates of temporary weight changes during Subperiod 1 were calculated from the weight regression equations established for the last 10 days of each period (Subperiods 2 and 3). The intercepts of these regressions immediately at the start and finish of each period were used to determine the expected body weight at each changeover. During the course of the experiment there were three changeovers (Periods 1 to 2; 2 to 3; and 3 to 4). Any difference between

intercepts at each changeover was regarded as the total temporary change in bodyweight. This procedure (similar to that used by Young (1975)) integrates the gradual changes in body weight which actually take place over several days.

(c) The effects of temperature on steady-state digestibility of energy, nitrogen, and dry matter, were analysed using the statistical model described in Section E. The same statistical model was used to determine the significance of changeovers on body weight; however, the degrees of freedom were modified to values shown in Table 7.

Results and Discussions

Animal Health and Climatic Environment

Details on temperatures, relative humidities, air movement, and animal health have been presented in Section E.

Feed Intake and Nutrient Digestibility

The feed actually consumed by the ad Libitum and restricted fed pigs, as well as the digestibilities of energy, nitrogen, and dry matter for each treatment combination, are summarized in Table 11 (raw data in Appendix B1 and B9). The absence of any effect of age on digestibility of energy, nitrogen, and dry matter in this experiment is supported by other studies on pigs of similar weight (Nielson, 1970; Fuller and Boyne, 1971, 1972; Thorbek, 1975) (AOV in Appendix C7, C8, and C9).

TABLE 11. SUMMARY OF DIGESTIBILITY RESULTS. A. FEED INTAKE, g/d·kg$^{0.75}$ (AS FED BASIS); B. DRY MATTER DIGESTIBILITY,%;C. NITROGEN DIGESTIBILITY,%;D. ENERGY DIGESTIBILITY,%.

Period	Code	Group 1		Group 2		Period Mean
		Restricted	ad Libitum	Restricted	ad Libitum	
1	A	99.3	128.0	101.3	115.0	112.3^a
	B	79.5	75.6	82.0	80.0	79.3
	C	77.6	68.7	78.6	77.7	75.5
	D	79.4	74.4	82.4	79.6	78.9
2	A	97.8	116.5	99.0	100.7	103.7^b
	B	81.4	80.3	78.2	76.7	79.3
	C	80.0	77.3	75.3	72.1	76.4
	D	80.5	78.6	77.0	75.3	78.0
3	A	99.3	103.3	96.8	99.3	99.7^b
	B	78.9	79.2	80.4	80.6	79.8
	C	77.6	75.2	81.6	80.0	78.6
	D	77.6	77.0	79.6	79.7	78.5
4	A	96.8	107.5	98.8	119.3	104.7^b
	B	80.5	80.5	78.7	78.4	79.6
	C	80.9	78.2	76.3	74.2	77.6
	D	80.0	78.7	77.7	77.1	78.4
Feed X Groups						
	A	98.1	113.8	98.9	109.1	
	B	80.2	78.9	79.8	79.1	
	C	79.2	74.8	78.0	76.1	
	D	79.5	77.2	79.2	78.1	
Period X Groups (Temperature)		6°C		21°C		
	A	99.1^a	112.8^b	98.2^a	109.6^c	
	B	78.9^a	77.5^a	81.1^b	80.4^b	
	C	76.7^a	72.6^a	80.3^b	78.4^b	
	D	77.9^a	76.0^a	80.6^b	79.2^b	

a,b,c Means in the same row or column with different letters are significantly different(**)

For all pigs exposed to 6^{o}C, the average digestibilities of dry matter, energy, and nitrogen (78.2, 77.0, 74.7%) were significantly lower (**) than for pigs exposed to 21^{o}C (80.8, 79.9, 79.4%) (Appendix C7, C8, C9). Studies on several species, including pigs, have reported reduced apparent digestibilities of energy, nitrogen, and dry matter at low temperature (Graham et al, 1959; Fuller and Boyne, 1971, 1972; Young and Christopherson, 1974; Kennedy et al,1976). Some results for animals of comparable size to the pig have been included in Table 12. The rates of reduction in digestibility associated with reduced ambient temperature observed in this study (about 0.25%/^{o}C), are in accord with those listed.

Although the pig does not rely on microbial activity for digestion as does the ruminant, a reduction in digestive retention time nevertheless might reduce the effectiveness of the nutrient extraction process, for example, by reducing exposure time to digestive enzymes. This type of response could be of adaptive significance in view of the increased requirement for more easily digestible material during cold where ample feed is available.

Restricted feeding consistently resulted in higher digestibility of energy, nitrogen, and dry matter as shown in Tables 11. However, feed level did not reach the chosen level of statistical significance (raw data in Appendix B9 and AOV's in Appendix C7, C8, C9). Graham et al (1959) found that increasing feeding level from maintenance to 1.5 times maintenance reduced energy digestibility in sheep. Fuller and Boyne (1971, 1972) found no change in digestibility of energy with increased feeding

TABLE 12. SUMMARY OF DIGESTIBILITY RESULTS FROM OTHER LOW TEMPERATURE STUDIES.

Study,Nutrient	Temperature		Change in Dig. per °C
Graham et al(1959),sheep:	8°C	23°C	
Energy			0.10%
Fuller and Boyne(1972),pigs:	4°C	23°C	
Energy	80.9%	83.0%	0.12
Nitrogen	82.2	83.6	0.08
Young and Christopherson (1974),calves:	-9°C	18°C	
Dry matter	62.9	70.1	0.27
Kennedy et al(1976),sheep:	0°C	20°C	
Dry matter	45.0	48.2	0.16
Organic Matter	47.7	51.1	0.17
Nitrogen	57.0	57.0	0.00
This study:	6°C	21°C	
Dry matter	78.2	80.8	0.17
Energy	77.0	79.9	0.19
Nitrogen	74.7	79.4	0.31

level in pigs, over a range of temperatures. At low temperatures (5° and 13°C), however, nitrogen digestibility fell with increased level of feeding; at 23°C feeding level had no effect on nitrogen digestibility. Peers et al (1977) kept growing pigs at either maintenance or 3 times maintenance feeding level at about 21°C, and found no change in digestibility of dry matter, energy, or nitrogen.

Since Cunningham et al (1962) have shown that concentration of dietary crude fibre can have considerable effect on digestibility of dry matter and nitrogen in pigs, one might expect a wide range of findings in the literature. The results of this study, although negative, do indicate consistently higher digestibility values for nitrogen, energy, and dry matter, for pigs restricted to about 88% of ad Libitum intake, on a barley-soybean meal based ration.

Weight Response to Acute Cold

Temporary bodyweight changes were calculated from liveweight records for each pig at each changeover and are listed in Table 13 as gains (+ kg) or losses (- kg). As average feed consumption for the ad Libitum fed pigs was higher at 6°C than at 21°C (AOV in Appendix C1), only the weight changes for the restricted pigs have been discussed in the remainder of this section.

The weight record for Pig No. 24 is shown in Figure 14 indicating the nature of the temporary body weight changes with each abrupt change in

TABLE 13. TEMPORARY CHANGE IN LIVEWEIGHT(kg) OF PIGS DURING FIVE DAYS AFTER CHANGEOVER.

	Group 1		Group 2	
	Restricted	ad Libitum	Restricted	ad Libitum
Temperature Chg.	6 to 21°C		21 to 6°C	
Mean Wt. Chg.	1.1	-0.7	-2.7	-2.8
Wt. Data*	2.6,-0.9,1.6,mg	1.2,0.9,-2.6,-2.4	-3.2,-0.3,-3.0,-4.4	mg,-3.4,-3.2,-1.9
Temperature Chg.	21 to 6°C		6 to 21°C	
Mean Wt. Chg.	-2.4	-1.2	0.7	-0.6
Wt. Data	-2.5,-3.4,mg,-1.2	-1.6,mg,-0.3,-1.6	-0.7,0.6,0.5,2.5	mg,-0.3,mg,-0.9
Temperature Chg.	6 to 21°C		21 to 6°C	
Mean Wt. Chg.	5.1	2.3	-1.7	-1.6
Wt. Data	5.7,5.7,mg,4.0	0.0,mg,2.5,4.4	-1.3,-2.2,-1.3,-2.0	mg,-1.8,mg,-1.3

mg , missing data

* respectively for Pigs 11-14,15-18,21-24,25-28.

temperature. As temperature was stepped down (21°C to 6°C) Pig 14 weight decreased 4.4 kg; as temperature was stepped up (6°C to 21°C) weight increased 2.5 kg; and during the last changeover down to 6°C again there was a weight loss of 2.0 kg. These values can be found in Table 13. Considering the average of the restricted pigs only, exposure to 6°C from 21°C resulted in an average temporary weight loss of 2.3 kg (std. dev. 2.44). Within 5 days of being returned to 21°C, the entire 2.3 kg (std. dev. 0.52) was regained (Appendix C10). These results are relevant to pigs from about 40 to 80 kg.

The temporary weight changes shown in Table 13 are quite independent of the reduced bodyweight gains noted in Section E. Further reference to Figure 14 can clarify this point. By extrapolation of the expected course of weight gain for Period 1 (21°C)(dashed line) to the end of Period 2 (6°C), point A represents the expected weight had no cold stress been applied. The difference between points A and B, in this case 3.6 kg, represents the permenant loss in weight due to 15 days at low temperature. The rate of loss, about 250 g/d, compares very closely to the difference in average daily gain for the 6 and 21°C pigs noted in Table 9 (280 g/d). The difference between points B and C represents a retrieval of weight temporarily lost when the pig was exposed to 6°C.

Although there is little information in the literature on this aspect of cold stress in pigs, a report by Hicks and Webster(1968) provides supporting evidence in that measured feed conversion efficiencies (units feed/units gain) at constant feeding level, for the 7-day period after exposure to 5°C, were 6 times higher than at 20°C. This may have

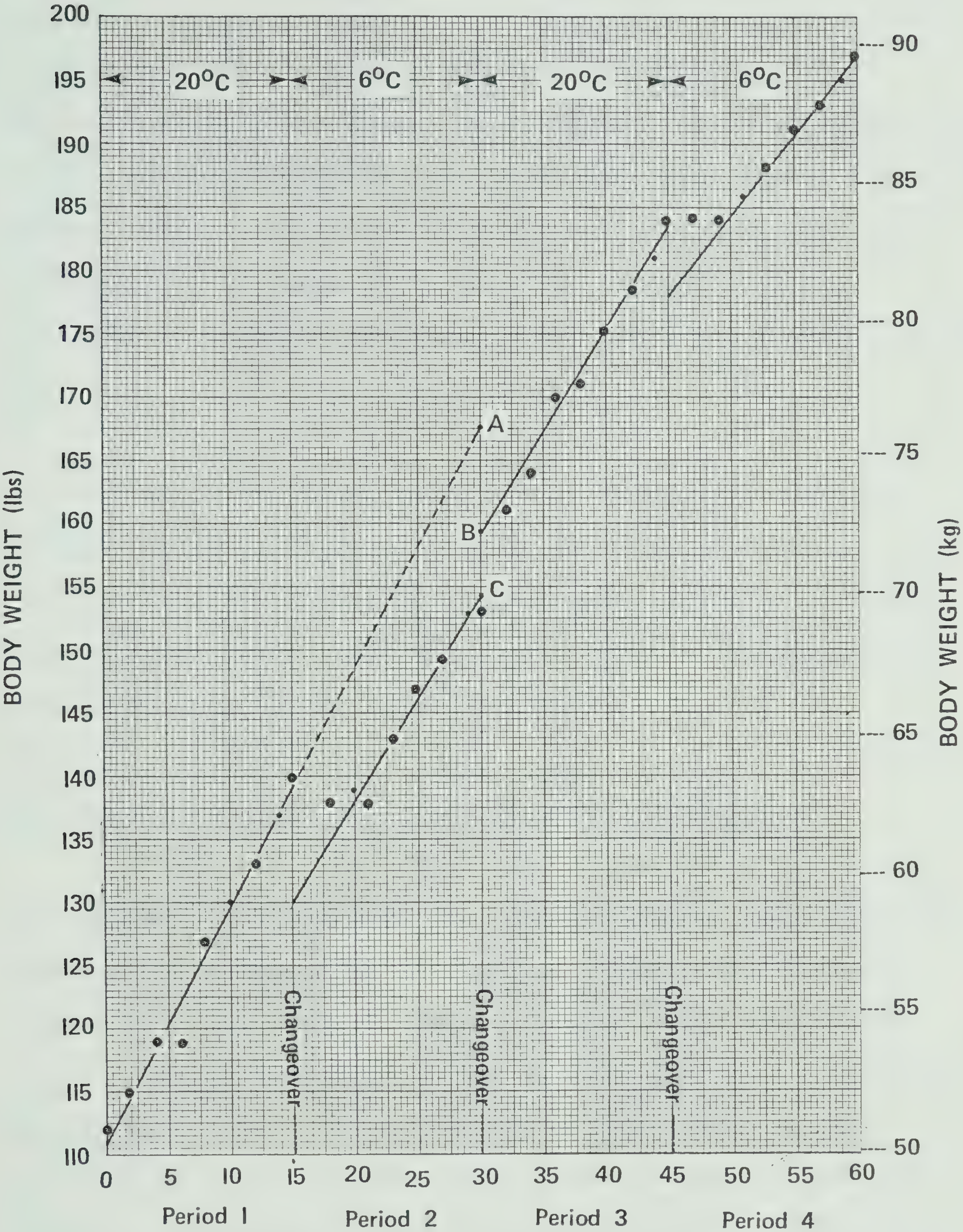

Figure 14. Weight gain regressions and intercepts for Pig 24 used in computing temporary weight change. (Period 2, 3, and 4 regressions based on the last 10 days of the period.)

arisen from temporary losses in bodyweight. The study by Holmes and Mount(1967) indicated a weight loss in growing pigs of about 2.5% of body weight within 4 days of changing from 20 to 9°C. Also Young(1975) found exposure to low temperature caused temporary bodyweight losses of up to 5% of body weight in cattle; body fluid shifts were cited as a possible adaptive physiological response which might be detected in liveweight. After eight days cold exposure in restricted fed sheep, Degen and Young(1979) found bodyweight reduced 7% and rumen fluid volume reduced by over 1 L.

From the results of this study, as well as others mentioned above, one might reasonably suspect a change in the volume of digesta to be at least partly responsible for the observed temporary body weight losses. Assuming this to be the case, the temporary change in bodyweight can be measured indirectly as described in the subsequent section.

Correlation of Digestive and Bodyweight Response to Acute Cold

Considering the throughput of a digestive tract in steady-state where feed dry matter intake is at constant rate (r), then fecal dry matter output will be some fraction of intake (k.r). If the digestive tract contains an amount of digesta, W, then it's retention time, R, equals the quotient W/r. Assuming this relationship is true, a reduction in R, as seems to occur at low temperature, must result in reduced W, if r remains constant. The difference between steady-state initial and final values for W represents a reduction in digestive amount ΔW, and as a consequence, a loss in liveweight of the same amount. Furthermore, the

need to change W undoubtedly will be manifest in the rates of fecal output, k.r, shortly after the temperature change.

The change in W for the pigs in this experiment has been determined by subtracting the actual wet fecal matter during Subperiod 1 from the expected wet fecal matter for Subperiod 1. The logic used for computing the expected wet fecal matter is based on adjusting the wet fecal matter for the previous subperiod upward, or downward, in proportion to any change in feed intake. If there is more wet fecal matter than expected, W is assumed to be decreasing and the liveweight of the pig is presumed to be reduced by the difference ΔW. If there is less wet fecal matter than expected, then the reverse is true.

Each particular element of the calculation mentioned above is shown in detail in Appendix A6. The resultant weight changes, ΔW kg,are shown in Table 14. Based on the mean of the restricted pigs, exposure to 6^{o}C from 21^{o}C resulted in an average weight loss of 1.06kg (std. dev. 0.88) during five days, while the return to 21^{o}C resulted in an average gain in weight of 1.83 kg (std. dev. 0.90) (AOV in Appendix C11).

Therefore, on the basis of this experiment, temperature-induced change in digestive volume may account for about half of the temporary liveweight changes observed; regression analysis indicates 55%. The correlation coefficient for the Group X Period means of ΔW and the temporary weight change for the restricted pigs is 0.92 indicating a very close relationship.

TABLE 14. TEMPORARY CHANGE IN WEIGHT OF FECAL OUTPUT(kg) FROM PIGS DURING FIVE DAYS AFTER CHANGEOVER.

	Group 1		Group 2	
	Restricted	ad Libitum	Restricted	ad Libitum
Temperature Chg.	6 to 21°C		21 to 6°C	
Mean Chg. in W	0.9	2.1	-2.0	-0.9
Data*	1.70, mg,0.1,mg	2.0,0.8,0.6,5.2	-2.2,-2.5,-1.2,-2.3	mg,1.0,1.7,1.1
Temperature Chg.	21 to 6°C		6 to 21°C	
Mean Chg. in W	-0.8	-1.1	1.9	0.4
Data	0.0,-1.8,mg,-0.7	0.7,-4.0,-1.8,0.5	1.5,1.5,1.8,3.0	mg,-0.6,1.3,mg
Temperature Chg.	6 to 21°C		21 to 6°C	
Mean Chg, in W	2.7	1.4	-0.3	-1.2
Data	4.2,2.6,mg,1.3	1.0,-0.9,4.4,1.1	0.3,0.1,-0.7,-1.1	mg,-1.4,-2.0,-0.2

mg, missing data

* respectively, for Pigs 11-14,15-18,21-24,25-28.

SECTION G

SUMMARY AND CONCLUSIONS

A review of the literature indicated the estimation of lower critical temperature can be an important decision-making aid in predicting energy losses in pigs exposed to low temperature. However, to date, ration formulation methods have made no allowances for temperature perhaps in part, because the effects of low temperature on body gains was not well understood.

A model that predicts the effects of low temperature on composition of body gains was developed. The model was compared against results from the literature and a feeding trial was carried out to test the protein deposition aspect of the model. While the model should receive further testing, both the above validity tests confirmed that low temperature reduces rate of tissue gain in pigs in a predictable manner.

The model also serves as a predictor of heat output rates, as related to level of feeding. Such information should be of value in the design of shelters for growing pigs, particularly if more North American pig producers adopt restricted feeding methods to improve feed conversion efficiency and conserve energy.

Results of the feeding trial were as follows:

1. Diminished weight gains, and protein gains, were observed in full fed and restricted fed pigs kept at low temperature but the monetary losses

associated with reduced weight gains may be offset to some extent as there was an increased proportion of protein in the daily tissue gain of pigs kept at low temperature.

2. Exposure of pigs to low temperature resulted in a reduction in digestibility of energy, nitrogen, and dry matter, of approximately one-quarter of one percent per Centigrade unit below 21^{o}C.

3. Abrupt temperature changes caused temporary changes in body weight. On average, a reduction in temperature from 21^{o} to 6^{o}C resulted in a temporary weight loss of about 4% of body weight. Five days after being returned to 21^{o}C this loss was regained entirely. These temporary changes may be due in part, to changes in gutfill. Although gutfill was not measured directly, some indirect evidence was presented as support for this possible explaination.

4. Feed restriction resulted in no improvement in digestibility of nitrogen, energy, or dry matter, as compared to ad Libitum feeding.

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APPENDIX A

PROCEDURES

APPENDIX A1

SAMPLE PROBLEM USING MODEL

Find the daily protein and lipid gains and heat outputs in a 50 kg growing hog housed at 20°C and 8°C and fed 2.1 kg/d of a ration containing 11 MJ/kg of metabolizable energy.

- Determine energy intake rate per unit metabolic body weight:

$$\text{Energy Intake} = (2.1\ \text{kg})(11{,}000\ \text{kJ/kg})/(50)^{0.75}$$
$$=1220\ \text{kJ}/(\text{d}\cdot\text{kg}^{0.75})$$

- Referring to Figure 11 find protein and lipid gain corresponding to 20°C at ME intake 1220 as follows:

Place the 45° line of the overlay on the 45° line of Figure 11. Keeping these matched, adjust the horizontal line of the overlay to correspond to 20°C on the temperature scale on the right of Figure 11.

Note the intersect of the horizontal line of the overlay and line Z of Figure 11 corresponds to feeding level E_L, while the horizontal line of the overlay intercects the 45° line at the critical feeding level E_C.

The production zone is now bounded by 4 lines: 1. the right margin of Figure 11, 2. the 45° line, 3. the horizontal line of the overlay between E_C and E_L, and 4. the Z line of Figure 11 to the right of E_L.

The protein and lipid gain can now be read off between the appropriate lines directly above the feeding level 1220 kJ/(d.kg$^{0.75}$) and heat output can be computed by difference:

Protein = 140 kJ/(d.kg$^{0.75}$) i.e. 112 g/d
Lipid = 420 kJ/(d.kg$^{0.75}$) i.e. 202 g/d
Heat Output Rate = 660 kJ/(d.kg$^{0.75}$) i.e. 12.4 MJ/d

- This procedure can now be repeated to find protein and lipid gain at 8°C and feeding level 1220:

Keeping the 45° line of the overlay matched with the 45° line of Figure 11 slide the overlay upward until the horizontal line of the overlay crosses 8°C on the temperature scale at the right of Figure 11.

Following the procedure outlined above, the protein and lipid gain can now be read off between the appropriate lines directly above 1220 kJ/(d.kg$^{0.75}$):

Protein = 125 kJ/(d.kg$^{0.75}$) i.e. 100 g/d
Lipid = 370 kJ/(d.kg$^{0.75}$) i.e. 178 g/d
Heat Output Rate = 725 kJ/(d.kg$^{0.75}$) i.e. 14.7 MJ/d

APPENDIX A2 . Energy partition data from Fuller and Boyne(1971,1972).

Temperature ^{o}C	Weight kg	Actual Feeding Rate	ME	Heat	Energy Retained	Pn	Fat	Marg. Eff. ER 55kg	Marg. Eff. ER 35 kg
		KJ/ day- $kg^{.75}$							
5	55	109	1355	960	395	102	293		
	35	109	1355	1035	320	117	203		
								0.81	0.56
	55	128	1591	1005	586				
	35	128	1591	1139	452				
								0.84	0.95
	55	145	1802	1040	762				
	35	145	1802	1152	650				
13	55	91	1131	797	334				
	35	91	1131	854	277				
								0.81	0.67
	55	110	1367	842	525	131	394		
	35	110	1367	931	436	167	269		
								0.84	0.91
	55	127	1579	876	703				
	35	127	1579	951	628				
23	55	74	932	569	363				
	35	74	932	611	321				
								0.72	0.85
	55	89	1129	624	505				
	35	89	1129	640	489				
								0.71	0.58
	55	108	1369	693	676	159	517		
	35	108	1369	740	629	211	418		

APPENDIX A3. FEED TABLES, lbs.

Pig Weight	Daily Feed
75.	3.11
76.	3.14
77.	3.17
78.	3.20
79.	3.23
80.	3.26
81.	3.29
82.	3.32
83.	3.35
84.	3.39
85.	3.42
86.	3.45
87.	3.48
88.	3.51
89.	3.54
90.	3.56
91.	3.59
92.	3.62
93.	3.65
94.	3.68
95.	3.71
96.	3.74
97.	3.77
98.	3.80
99.	3.83
100.	3.86
101.	3.89
102.	3.92
103.	3.94
104.	3.97
105.	4.00
106.	4.03
107.	4.06
108.	4.09
109.	4.12
110.	4.14
111.	4.17
112.	4.20
113.	4.23
114.	4.26
115.	4.28
116.	4.31
117.	4.34
118.	4.37
119.	4.40
120.	4.42
121.	4.45
122.	4.48
123.	4.51
124.	4.53

APPENDIX A3. FEED TABLES(CONT'D), lbs.

Pig Weight	Daily Feed
125.	4.56
126.	4.59
127.	4.62
128.	4.64
129.	4.67
130.	4.70
131.	4.72
132.	4.75
133.	4.78
134.	4.80
135.	4.83
136.	4.86
137.	4.89
138.	4.91
139.	4.94
140.	4.97
141.	4.99
142.	5.02
143.	5.05
144.	5.07
145.	5.10
146.	5.12
147.	5.15
148.	5.18
149.	5.20
150.	5.23
151.	5.26
152.	5.28
153.	5.31
154.	5.33
155.	5.36
156.	5.39
157.	5.41
158.	5.44
159.	5.46
160.	5.49
161.	5.51
162.	5.54
163.	5.57
164.	5.59
165.	5.62
166.	5.64
167.	5.67
168.	5.69
169.	5.72
170.	5.74
171.	5.77
172.	5.79
173.	5.82
174.	5.84

APPENDIX A3. FEED TABLES(CONT'D), lbs.

Pig Weight	Daily Feed
175.	5.87
176.	5.90
177.	5.92
178.	5.95
179.	5.97
180.	6.00
181.	6.02
182.	6.05
183.	6.07
184.	6.09
185.	6.12
186.	6.14
187.	6.17
188.	6.19
189.	6.22
190.	6.24
191.	6.27
192.	6.29
193.	6.32
194.	6.34
195.	6.37
196.	6.39
197.	6.42
198.	6.44
199.	6.46
200.	6.49
201.	6.51
202.	6.54
203.	6.56
204.	6.59
205.	6.61
206.	6.63
207.	6.66
208.	6.68
209.	6.71
210.	6.73
211.	6.75
212.	6.78
213.	6.80
214.	6.83
215.	6.85
216.	6.87
217.	6.90
218.	6.92
219.	6.95
220.	6.97

APPENDIX A4

Catheter Implantation Procedure (about 15 minutes)

1. Pig removed from cage to lab in adjacent building.
2. Pig secured in sling about 1 m above floor.
3. Posterior area of pig washed with disinfectant.
4. Disinfection of hands and equipment (speculum, wire).
5. Lubricate wire and insert catheter.
6. Insert lubricated speculum in vagina to observe urethra.
7. Remove catheter with the support wire from the sterile wrap.
8. Dip catheter tip in sterile lubricant.
9. Slide catheter up urethra.
10. Withdraw support wire and check that urine is flowing.
11. Inflate catheter with 25 cc tap water.
12. Connect 2 m flexible 10 mm I.D. tubing to catheter outlet.
13. Secure the catheter-tubing connection to tail with adhesive tape.
14. Return pig to cage.

APPENDIX A5

Journal of Individual Pigs

A. Events common to all pigs.

Time	Date	Remarks
12:00	23 May	Arrival of pigs at experimental site.
16:00	31 May	Switched groups between rooms.
16:00	9 June	Switched groups between rooms.
16:00	15 June	Start of experimental program.
20:00	28 June	3 cc Penicillum G to all pigs.
16:00	30 June	End of Period I.
20:00	10 July	3 cc Penicillum G to all pigs.
16:00	15 July	End of Period II.
16:00	29 July	3 cc Combiotic to all pigs.
16:00	30 July	End of Period III.
16:00	14 Augt	End of Period IV.

B. Individual Pig Journals.

Pig	Time	Date	Period	Subperiod	Remarks
1	16:00	21 June	1	2	Catheter Implanted.
	16:00	15 July	2	3	Catheter removed; rectum protruding.
	16:00	20 July	3	2	Catheter Implanted.
12	16:00	20 June	1	2	Catheter implanted.
	16:00	28 June	1	3	Catheter removed; rectum protruding.
	16:00	10 July	2	3	Catheter Implanted.
13	16:00	23 June	1	2	Catheter implanted.
	16:00	1 July	2	1	Catheter removed;rectum protruding.
	16:00	5 July	2	2	Catheter implanted.
	16:00	10 July	2	3	Catheter removed;rectum protruding.
	16:00	9 Augt	4	3	Catheter implanted.
14	16:00	20 June	1	2	Catheter implanted.
	7:00	25 June	1	2	Prolapsed rectum;pig and data discarded.
	12:00	28 June	1	3	New pig No. 14.
	16:00	1 July	2	1	Catheter implanted.
15	16:00	23 June	1	2	Catheter implanted.
	16:00	27 July	3	3	Catheter removed;plugged for 6 hours.
	16:00	4 Augt	4	1	Catheter implanted.

Pig	Time	Date	Period	Subperiod	Remarks
16	16:00	21 June	1	2	Catheter implanted.
	16:00	27 July	3	3	Catheter removed;blood in urine.
	16:00	4 Augt	4	2	Catheter implanted.
17	16:00	21 June	1	2	Catheter implanted.
	05:00	3 July	2	1	Catheter removed;rectum protruding.
	16:00	10 July	2	3	Catheter implanted.
18	16:00	10 June	1	2	Catheter implanted.
21	16:00	24 June	1	2	Catheter implanted.
	13:00	1 July	2	1	Catheter removed;rectum protruding.
	16:00	5 July	2	2	Catheter Implanted.
	16:00	10 July	2	3	Catheter removed; rectum protruding.
	16:00	25 July	3	3	Catheter implanted.
	20:00	11 Augt	4	3	Prolapsed rectum;pig discarded.
22	16:00	22 June	1	2	Catheter implanted.
23	16:00	22 June	1	2	Catheter implanted.
	06:00	7 July	2	2	Catheter removed; rectum protruding.
	16:00	10 July	2	3	Catheter implanted.
24	16:00	20 June	1	2	Catheter implanted.
	16:00	5 July	2	2	Catheter removed; diarrhea.
	16:00	10 July	2	3	Catheter implanted.
25	16:00	15 June	1	1	Catheter implanted.
	06:00	28 June	1	3	Prolapsed rectum; pig discarded.
26	16:00	22 June	1	2	Catheter implanted.
	16:00	10 July	2	3	Catheter removed; blood in urine.
	16:00	20 July	3	2	Catheter implanted.
27	16:00	20 June	1	2	Catheter implanted.
	16:00	15 July	2	3	Catheter removed; plugged for 12 hrs.
	16:00	25 July	3	2	Catheter implanted.
28	16:00	22 June	1	2	Catheter implanted.
	16:00	12 July	2	3	Catheter removed; unknown aliment.
	16:00	20 July	2	3	Catheter implanted.

APPENDIX A6. TEMPORARY CHANGE IN FECAL OUTPUT DURING THE FIVE DAYS AFTER TEMPERATURE CHANGE. (P, period; SP, subperiod, AWF, Actual wet feces;EWF, expected wet feces).

Changeover	Group 1								Group 2							
	Feed 1				Feed 2				Feed 1				Feed 2			
ΔW	11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
				6 to 21°C									21 to 6°C			
AWF(P1SP3)kg/d	1.06	mg	0.92	mg	1.67	1.61	1.51	2.63	1.21	0.97	1.01	1.27	mg	0.99	1.70	1.05
Feed Increase	1.09		1.06		1.10	1.06	0.94	0.96	1.05	1.07	1.05	1.05		1.04	1.04	1.08
EWF(P2SP1)kg.d	1.16		0.98		1.84	1.71	1.42	2.52	1.27	1.05	1.06	1.33		1.03	1.77	1.13
AWF(P2SP1)kg/d	0.82		0.97		1.45	1.56	1.30	1.48	1.70	1.54	1.30	1.79		1.12	2.20	1.14
ΔW(EWF-AWF)*5	1.70		0.05		1.95	0.75	0.61	5.20	-2.15	-2.45	-1.20	-2.30		-0.45	-2.15	-0.05
				21 to 6°C									6 to 21°C			
AWF(P2SP3)	1.38	1.35	mg	1.11	1.86	1.20	1.77	2.41	1.75	1.59	1.30	1.59	mg	1.34	1.81	mg
Feed Increase	1.00	1.00		1.00	0.89	0.97	0.97	0.99	0.87	1.00	1.04	1.02		0.80	0.59	
EWF(P3SP1)	1.38	1.35		1.11	1.65	1.16	1.72	2.39	1.52	1.59	1.35	1.62		1.07	1.07	
AWF(P3SP1)	1.38	1.70		1.25	1.51	1.95	2.08	2.29	1.22	1.30	1.00	1.02		1.18	0.81	
ΔW(EWF-AWF)*5	0.00	-1.75		-0.70	0.70	-3.95	-1.80	0.50	1.50	1.45	1.75	3.00		-0.55	1.30	
				6 to 21 °C									21 to 6°C			
AWF(P3SP3)	2.04	1.64	mg	1.46	1.61	0.85	2.31	2.48	1.78	1.56	1.34	1.79	mg	1.38	1.31	1.89
Feed Increase	1.04	1.05		1.05	1.26	2.01	1.13	0.99	1.02	1.03	1.04	1.03		0-97	1.40	1.10
EWF(P4SP1)	2.12	1.72		1.54	2.03	1.72	2.61	2.46	1.81	1.61	1.40	1.85		1.33	1.83	2.08
AWF(P4SP1)	1.28	1.20		1.29	1.83	1.89	1.73	2.24	1.75	1.59	1.53	2.06		1.60	2.23	2.12
ΔW(EWF-AWF)*5	4.20	2.60		1.25	1.00	-0.85	4.40	1.10	0.30	0.10	-0.65	-1.05		-1.35	-2.00	-0.20

mg - missing observation

APPENDIX B.

RAW DATA

Appendix B1

FEED, GM/SUB-PERIOD

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
8097.	8827.	8596.	-99.	7693.	11330.	11980.	10120.	8912.	9140.	7756.	9689.	11870.	11040.	11440.	9910.
6704. (4)*	9099.	3560. (2)	-99.	4146. (2)	9596. (4)	7792. (4)	10310.	1950. (1)	5679. (3)	5186. (3)	10180.	12660.	5646. (3)	7317. (3)	6390. (3)
8564.	-99.	9099.	-99.	10930.	12510.	11900.	13620.	10150.	10080.	9058.	10820.	-99.	9930.	12850.	8540.
9117.	9720.	9471.	8623.	11780.	12860.	10250.	12900.	10410.	10450.	9222.	11220.	-99.	10070.	12990.	10000.
9838.	10315.	10040.	9349.	12510.	10690.	13750.	14270.	10460.	10570.	9380.	11280.	-99.	7820.	12730.	10190.
10330.	10900.	10510.	9910.	11610.	12150.	13250.	15810.	10790.	10910.	9730.	11800.	-99.	11740.	11160.	11310.
10580.	11250.	10800.	10250.	10620.	12010.	13170.	16060.	9610.	11280.	10310.	12350.	-99.	9620.	6710.	13090.
10700.	11260.	-99.	10390.	10200.	10520.	7450.	15690.	10780.	11690.	8090.	12990.	-99.	7090.	3620.	9780.
11060.	11490.	-99.	10700.	10840.	6790.	14820.	17780.	12140.	12160.	11000.	13450.	-99.	10970.	11200.	12860.
11520.	12050.	-99.	11200.	13690.	13660.	16800.	17560.	12460.	12480.	11510.	13830.	-99.	10620.	15470.	14160.
12310.	12800.	-99.	11850.	14060.	13630.	15620.	16280.	12640.	12610.	11550.	13950.	-99.	14940.	16250.	16100.
12910.	13240.	10360.	12360.	12330.	13360.	14270.	14880.	-99.	12850.	11950.	14280.	-99.	14630.	16430.	16380.

-99., missing data

* denotes where feed consumed is based on some value other than five days

FEED CONSUMPTION,GM/DAY-KG.75

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	98.	0.	0.	0.	0.	0.	97.	0.	0.	0.	95.	131.	0.	0.	0.
100.	0.	100.	0.	138.	137.	124.	129.	103.	102.	102.	101.	0.	102.	132.	95.
89.	0.	0.	69.	119.	119.	0.	105.	0.	97.	97.	97.	0.	97.	119.	101.
96.	0.	97.	96.	126.	99.	0.	117.	98.	98.	0.	0.	0.	76.	117.	103.
101.	102.	0.	102.	117.	113.	118.	129.	0.	101.	102.	102.	0.	0.	103.	0.
0.	98.	0.	97.	99.	105.	106.	118.	0.	94.	94.	93.	0.	0.	0.	0.
98.	98.	0.	98.	95.	92.	60.	116.	0.	97.	74.	97.	0.	0.	0.	86.
101.	101.	0.	101.	0.	0.	120.	131.	102.	101.	101.	101.	0.	97.	102.	113.
91.	92.	0.	92.	0.	0.	119.	115.	98.	98.	97.	98.	0.	86.	120.	113.
97.	98.	0.	98.	114.	107.	111.	107.	100.	99.	97.	98.	0.	121.	126.	128.
102.	101.	96.	102.	100.	105.	101.	98.	0.	101.	101.	101.	0.	119.	128.	130.

0., missing data

FEED CONSUMPTION,GM/DAY-KG.75 (Period Means)

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
100.	98.	100.	0.	138.	137.	124.	113.	103.	102.	102.	98.	131.	102.	132.	95.
96.	102.	97.	96.	121.	110.	118.	117.	98.	99.	100.	99.	0.	87.	113.	102.
100.	99.	0.	99.	97.	99.	95.	122.	102.	98.	90.	97.	0.	97.	102.	99.
97.	97.	96.	97.	107.	106.	111.	106.	99.	99.	98.	99.	0.	109.	125.	124.

0., missing data

Appendix B2

SUB-PERIOD RATION TYPE: G=GROWER, F= FINISHER, M= BOTH G AND F

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
G	G	G		G	G	G	M	G	G	G	G	G	G	G	G
G	G	G		G	G	G	F	G	G	G	M	G	G	G	G
G		G		G	G	M	F	F	M	G	F		M	M	G
G	G	G	G	G	G	F	F	F	F	G	F		F	F	G
M	F	M	G	G	F	F	F	F	F	G	F		F	F	G
F	F	F	M	M	F	F	F	F	F	M	F		F	F	M
F	F	F	F	F	F	F	F	F	F	F	F		F	F	F
F	F		F	F	F	F	F	F	F	F	F		F	F	F
F	F		F	F	F	F	F	F	F	F	F		F	F	F
F	F		F	F	F	F	F	F	F	F	F		F	F	F
F	F		F	F	F	F	F	F	F	F	F		F	F	F
F	F	F	F	F	F	F	F	F	F	F	F		F	F	F

PROTEIN FRACTION OF FEED

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.1742	0.1742	0.1742	0.0	0.1742	0.1742	0.1742	0.1669	0.1742	0.1742	0.1742	0.1742	0.1742	0.1742	0.1742	0.1742
0.1633	0.1633	0.1633	0.0	0.1633	0.1633	0.1633	0.1669	0.1633	0.1633	0.1633	0.1581	0.1633	0.1633	0.1633	0.1633
0.1567	0.0	0.1567	0.0	0.1567	0.1567	0.1495	0.1204	0.1204	0.1349	0.1567	0.1204	0.0	0.1495	0.1495	0.1567
0.1538	0.1538	0.1538	0.1538	0.1538	0.1538	0.1146	0.1146	0.1146	0.1146	0.1538	0.1146	0.0	0.1146	0.1146	0.1538
0.1600	0.1536	0.1600	0.1656	0.1656	0.1536	0.1536	0.1536	0.1536	0.1536	0.1656	0.1536	0.0	0.1536	0.1536	0.1656
0.1807	0.1807	0.1807	0.1600	0.1600	0.1807	0.1807	0.1807	0.1807	0.1807	0.1600	0.1807	0.0	0.1807	0.1807	0.1600
0.1648	0.1648	0.1648	0.1648	0.1648	0.1648	0.1648	0.1648	0.1648	0.1648	0.1648	0.1648	0.0	0.1648	0.1648	0.1648
0.1682	0.1682	0.0	0.1682	0.1682	0.1682	0.1682	0.1682	0.1682	0.1682	0.1682	0.1682	0.0	0.1682	0.1682	0.1682
0.1655	0.1655	0.0	0.1655	0.1655	0.1655	0.1655	0.1655	0.1655	0.1655	0.1655	0.1655	0.0	0.1655	0.1655	0.1655
0.1674	0.1674	0.0	0.1674	0.1674	0.1674	0.1674	0.1674	0.1674	0.1674	0.1674	0.1674	0.0	0.1674	0.1674	0.1674
0.1504	0.1504	0.0	0.1504	0.1504	0.1504	0.1504	0.1504	0.1504	0.1504	0.1504	0.1504	0.0	0.1504	0.1504	0.1504
0.1661	0.1661	0.1661	0.1661	0.1661	0.1661	0.1661	0.1661	0.0	0.1661	0.1661	0.1661	0.0	0.1661	0.1661	0.1661

0., missing data

DRY MATTER FRACTION OF FEED

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.869	0.869	0.869	0.0	0.869	0.869	0.869	0.869	0.864	0.869	0.869	0.869	0.869	0.869	0.869	0.869
0.867	0.867	0.867	0.0	0.867	0.867	0.867	0.863	0.867	0.867	0.867	0.867	0.867	0.867	0.867	0.867
0.874	0.0	0.874	0.0	0.874	0.874	0.869	0.864	0.864	0.869	0.874	0.864	0.0	0.869	0.869	0.874
0.880	0.880	0.880	0.880	0.880	0.880	0.875	0.875	0.875	0.875	0.880	0.875	0.0	0.875	0.875	0.880
0.888	0.887	0.888	0.888	0.888	0.887	0.887	0.887	0.887	0.887	0.888	0.887	0.0	0.887	0.887	0.888
0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.0	0.888	0.888	0.888
0.868	0.868	0.868	0.868	0.868	0.868	0.868	0.868	0.868	0.868	0.868	0.868	0.0	0.868	0.868	0.868
0.867	0.867	0.0	0.867	0.867	0.867	0.867	0.867	0.867	0.867	0.867	0.867	0.0	0.867	0.867	0.867
0.859	0.859	0.0	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.0	0.859	0.859	0.859
0.858	0.858	0.0	0.858	0.858	0.858	0.858	0.858	0.858	0.858	0.858	0.858	0.0	0.858	0.858	0.858
0.874	0.874	0.0	0.874	0.874	0.874	0.874	0.874	0.874	0.874	0.874	0.874	0.0	0.874	0.874	0.874
0.872	0.872	0.872	0.872	0.872	0.872	0.872	0.872	0.0	0.872	0.872	0.872	0.0	0.872	0.872	0.872

0., missing data

Appendix B2

FEED PROTEIN, GM/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
282.	308.	299.	0.	268.	395.	417.	338.	310.	318.	270.	338.	414.	385.	399.	345.
0.	297.	0.	0.	0.	0.	0.	344.	0.	0.	0.	322.	413.	0.	0.	0.
271.	0.	287.	0.	341.	392.	339.	328.	257.	286.	283.	261.	0.	301.	389.	298.
280.	299.	291.	265.	362.	396.	235.	296.	239.	240.	284.	257.	0.	231.	298.	308.
315.	317.	321.	310.	414.	328.	422.	438.	321.	325.	311.	347.	0.	240.	391.	337.
373.	394.	380.	317.	372.	439.	479.	571.	390.	394.	311.	426.	0.	424.	403.	362.
349.	371.	356.	336.	350.	396.	434.	529.	317.	372.	340.	407.	0.	317.	221.	431.
360.	379.	0.	350.	343.	354.	251.	528.	363.	393.	272.	437.	0.	239.	122.	329.
366.	380.	0.	354.	359.	225.	491.	589.	402.	402.	364.	445.	0.	363.	371.	426.
386.	403.	0.	375.	458.	457.	562.	588.	417.	418.	385.	463.	0.	356.	518.	474.
370.	385.	0.	356.	423.	410.	470.	490.	380.	379.	347.	420.	0.	449.	489.	484.
429.	440.	344.	411.	410.	444.	474.	494.	0.	427.	397.	474.	0.	486.	546.	544.

0., missing data

FEED DRY MATTER,GM/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
1407.	1534.	1494.	0.	1337.	1969.	2082.	1759.	1540.	1589.	1348.	1684.	2063.	1919.	1988.	1722.
0.	1578.	0.	0.	0.	0.	0.	1780.	0.	0.	0.	1765.	2195.	0.	0.	0.
1477.	0.	1577.	0.	1898.	2139.	1900.	2354.	1743.	1710.	1552.	1870.	0.	1691.	2189.	1626.
1605.	1711.	1667.	1518.	2073.	2263.	1794.	2258.	1822.	1829.	1623.	1964.	0.	1762.	2273.	1760.
1747.	1830.	1783.	1660.	2222.	1896.	2439.	2531.	1856.	1875.	1666.	2001.	0.	1387.	2258.	1810.
1835.	1936.	1867.	1760.	2062.	2198.	2353.	2808.	1916.	1938.	1728.	2096.	0.	2085.	1982.	2009.
1837.	1953.	1875.	1779.	1844.	2085.	2286.	2788.	1668.	1958.	1790.	2144.	0.	1670.	1165.	2272.
1855.	1952.	0.	1802.	1769.	1824.	1292.	2721.	1869.	2027.	1403.	2252.	0.	1229.	628.	1696.
1900.	1974.	0.	1838.	1862.	1167.	2546.	3055.	2086.	2089.	1890.	2311.	0.	1885.	1924.	2209.
1977.	2068.	0.	1922.	2349.	2344.	2883.	3013.	2138.	2142.	1975.	2373.	0.	1822.	2655.	2430.
2152.	2237.	0.	2071.	2458.	2383.	2730.	2846.	2209.	2204.	2019.	2438.	0.	2612.	2841.	2814.
2252.	2309.	1807.	2156.	2150.	2330.	2489.	2595.	0.	2241.	2084.	2490.	0.	2551.	2865.	2857.

0., missing data

Appendix B2

GROSS ENERGY IN FEED, CAL/GM

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
3723.	3723.	3723.	0.	3723.	3723.	3723.	3735.	3723.	3723.	3723.	3723.	3723.	3723.	3723.	3723.
3714.	3714.	3714.	0.	3714.	3714.	3714.	3753.	3714.	3714.	3714.	3725.	3714.	3714.	3714.	3714.
3793.	0.	3793.	0.	3793.	3793.	3785.	3776.	3776.	3785.	3793.	3776.	0.	3785.	3785.	3793.
3812.	3812.	3812.	3812.	3812.	3812.	3815.	3815.	3815.	3815.	3812.	3815.	0.	3815.	3815.	3812.
3800.	3784.	3800.	3838.	3858.	3784.	3784.	3784.	3784.	3784.	3838.	3784.	0.	3784.	3784.	3838.
3735.	3735.	3735.	3750.	3780.	3735.	3735.	3735.	3735.	3735.	3800.	3735.	0.	3735.	3735.	3750.
3820.	3820.	3820.	3820.	3820.	3820.	3820.	3820.	3820.	3820.	3820.	3820.	0.	3820.	3820.	3820.
3806.	3806.	0.	3806.	3806.	3806.	3806.	3806.	3806.	3806.	3806.	3806.	0.	3806.	3806.	3806.
3815.	3815.	0.	3815.	3815.	3815.	3815.	3815.	3815.	3815.	3815.	3815.	0.	3815.	3815.	3815.
3814.	3814.	0.	3814.	3814.	3814.	3814.	3814.	3814.	3814.	3814.	3814.	0.	3814.	3814.	3814.
3840.	3840.	0.	3840.	3840.	3840.	3840.	3840.	3840.	3840.	3840.	3840.	0.	3840.	3840.	3840.
3847.	3847.	3847.	3847.	3847.	3847.	3847.	3847.	0.	3847.	3847.	3847.	0.	3847.	3847.	3847.

0., missing data

FEED ENERGY,KJ/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
25201.	27473.	26784.	0.	23944.	35264.	37287.	31599.	27738.	28448.	24140.	30156.	36945.	34361.	35606.	30844.
0.	28252.	0.	0.	0.	0.	0.	32348.	0.	0.	0.	31702.	39308.	0.	0.	0.
26651.	0.	28504.	0.	33951.	38591.	34360.	42995.	31746.	30955.	28015.	34156.	0.	30595.	39612.	29325.
29054.	30976.	30182.	27480.	37541.	40983.	32691.	41142.	33201.	33329.	29389.	35784.	0.	32117.	41430.	31868.
31253.	32631.	31895.	29997.	40348.	33817.	43497.	45142.	33089.	33437.	30096.	35683.	0.	24738.	40270.	32695.
32255.	34035.	32817.	31068.	36397.	37938.	41373.	49366.	33691.	34066.	30910.	36845.	0.	36658.	34847.	35457.
33787.	35927.	34490.	32734.	33915.	38354.	42059.	51288.	30690.	36023.	32925.	39440.	0.	30722.	21429.	41803.
34045.	35827.	0.	33059.	32455.	33473.	23705.	49923.	34300.	37195.	25741.	41332.	0.	22559.	11518.	31118.
35274.	36646.	0.	34126.	34572.	21656.	47266.	56706.	38719.	38782.	35083.	42897.	0.	34987.	35721.	41015.
36732.	38421.	0.	35711.	43651.	43555.	53567.	55990.	39729.	39793.	36700.	44097.	0.	33862.	49326.	45149.
39518.	41091.	0.	38041.	45136.	43756.	50144.	52263.	40577.	40481.	37078.	44783.	0.	47961.	52166.	51685.
41520.	42581.	33319.	39751.	39654.	42967.	45894.	47855.	0.	41327.	38432.	45926.	0.	47051.	52840.	52680.

0., missing data

Appendix B3

DIGESTIBLE ENERGY,KJ/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	20947.	0.	0.	0.	0.	0.	19198.	0.	0.	0.	27005.	29631.	0.	0.	0.
21084.	0.	24204.	0.	26161.	31086.	26401.	28621.	26859.	25508.	22393.	27400.	0.	24248.	34084.	22800.
24906.	0.	0.	23108.	30691.	33411.	0.	32353.	0.	26014.	21989.	27230.	0.	24916.	31451.	24936.
25360.	0.	25447.	25471.	32459.	26323.	0.	33666.	26352.	26047.	0.	0.	0.	19550.	30814.	23023.
24938.	26839.	0.	25786.	29762.	32336.	31840.	36988.	0.	26006.	23045.	28220.	0.	0.	26631.	0.
0.	27640.	0.	26196.	26876.	29721.	31955.	39574.	0.	29495.	27166.	33677.	0.	0.	0.	0.
27106.	27936.	0.	25002.	25323.	25926.	18460.	37102.	0.	30004.	20573.	32758.	0.	0.	0.	24752.
26643.	28394.	0.	26692.	0.	0.	36223.	43245.	30518.	30704.	28143.	34357.	0.	27905.	28898.	31760.
31064.	32037.	0.	29644.	0.	0.	44012.	44008.	30977.	31390.	28703.	33858.	0.	25575.	38354.	34173.
32466.	32484.	0.	31579.	36183.	35301.	39752.	40830.	31330.	32192.	28635.	34443.	0.	38762.	40543.	38869.
33019.	33123.	26548.	31375.	30365.	34496.	35399.	36890.	0.	32254.	29620.	36015.	0.	35812.	40898.	39736.

0., missing data

DIGESTIBLE ENERGY,KJ/DAY-KG.75

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	1126.	0.	0.	0.	0.	0.	908.	0.	0.	0.	1256.	1537.	0.	0.	0.
1232.	0.	1336.	0.	1654.	1697.	1377.	1353.	1358.	1293.	1262.	1274.	0.	1247.	1745.	1262.
1220.	0.	0.	1188.	1549.	1550.	0.	1321.	0.	1208.	1156.	1173.	0.	1206.	1444.	1257.
1242.	0.	1225.	1310.	1639.	1221.	0.	1375.	1233.	1210.	0.	0.	0.	946.	1415.	1161.
1221.	1251.	0.	1326.	1502.	1500.	1417.	1511.	0.	1208.	1211.	1216.	0.	0.	1223.	0.
0.	1209.	0.	1237.	1253.	1300.	1291.	1459.	0.	1228.	1243.	1263.	0.	0.	0.	0.
1240.	1222.	0.	1180.	1181.	1134.	746.	1368.	0.	1249.	941.	1228.	0.	0.	0.	1085.
1219.	1242.	0.	1260.	0.	0.	1464.	1594.	1277.	1278.	1288.	1288.	0.	1239.	1311.	1392.
1226.	1224.	0.	1220.	0.	0.	1563.	1443.	1222.	1232.	1211.	1194.	0.	1037.	1490.	1359.
1282.	1241.	0.	1299.	1467.	1389.	1411.	1339.	1236.	1263.	1208.	1214.	0.	1572.	1575.	1545.
1303.	1266.	1233.	1291.	1231.	1398.	1257.	1209.	0.	1266.	1249.	1270.	0.	1452.	1589.	1580.

0., missing data

DIGESTIBLE ENERGY,KJ/DAY-KG.75 (Period means)

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
1232.	1126.	1336.	0.	1654.	1697.	1377.	1130.	1358.	1293.	1262.	1265.	1537.	1247.	1745.	1262.
1228.	1251.	1225.	1275.	1563.	1424.	1417.	1402.	1233.	1209.	1183.	1195.	0.	1076.	1361.	1209.
1230.	1224.	0.	1226.	1217.	1217.	1167.	1474.	1277.	1252.	1157.	1260.	0.	1239.	1311.	1239.
1270.	1244.	1233.	1270.	1349.	1373.	1410.	1330.	1229.	1253.	1223.	1226.	0.	1353.	1551.	1495.

0., missing data

Appendix B3

METABOLIZABLE ENERGY,KJ/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	19821.	0.	0.	0.	0.	0.	18619.	0.	0.	0.	26068.	28312.	0.	0.	0.
20011.	0.	23494.	0.	25104.	29547.	25519.	27982.	25765.	24408.	21224.	26510.	0.	23206.	32546.	22009.
23837.	0.	0.	22076.	29610.	31900.	0.	31646.	0.	24973.	21021.	26515.	0.	24173.	30267.	23928.
24533.	0.	24800.	24488.	31364.	25436.	0.	32847.	25558.	24751.	0.	0.	0.	18807.	29413.	22153.
24168.	25973.	0.	24556.	28566.	31457.	30779.	35907.	0.	24827.	21902.	27212.	0.	0.	25347.	0.
0.	26653.	0.	25029.	25923.	28457.	30796.	38325.	0.	28546.	26315.	32663.	0.	0.	0.	0.
26243.	20643.	0.	23761.	24084.	24651.	17321.	35606.	0.	28642.	19635.	31538.	0.	0.	0.	23965.
25646.	27370.	0.	25631.	0.	0.	35164.	41738.	29462.	29542.	27225.	33207.	0.	27106.	28000.	30872.
29914.	30802.	0.	28309.	0.	0.	42357.	42211.	29629.	29722.	27667.	32619.	0.	24651.	36889.	32892.
31149.	31223.	0.	30131.	34876.	34093.	38160.	39227.	30133.	30458.	27631.	33106.	0.	37282.	38972.	37413.
31670.	31698.	25387.	29748.	28839.	33050.	33524.	35072.	0.	30279.	28612.	34884.	0.	34227.	39142.	38100.

0., missing data

METABOLIZABLE ENERGY,KJ/DAY-KG,75

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	1065.	0.	0.	0.	0.	0.	880.	0.	0.	0.	1212.	1468.	0.	0.	0.
1169.	0.	1296.	0.	1587.	1613.	1331.	1323.	1302.	1237.	1196.	1233.	0.	1193.	1666.	1218.
1168.	0.	0.	1135.	1495.	1480.	0.	1292.	0.	1160.	1105.	1142.	0.	1170.	1390.	1206.
1202.	0.	1194.	1259.	1583.	1180.	0.	1342.	1196.	1150.	0.	0.	0.	910.	1351.	1117.
1184.	1211.	0.	1263.	1442.	1499.	1370.	1466.	0.	1153.	1151.	1172.	0.	0.	1164.	0.
0.	1166.	0.	1182.	1209.	1245.	1245.	1413.	0.	1189.	1204.	1225.	0.	0.	0.	0.
1201.	1165.	0.	1122.	1123.	1078.	700.	1313.	0.	1192.	898.	1182.	0.	0.	0.	1051.
1174.	1197.	0.	1210.	0.	0.	1421.	1539.	1233.	1230.	1246.	1245.	0.	1204.	1270.	1353.
1181.	1177.	0.	1169.	0.	0.	1504.	1384.	1168.	1166.	1167.	1150.	0.	999.	1433.	1308.
1230.	1193.	0.	1240.	1414.	1342.	1355.	1286.	1188.	1195.	1166.	1167.	0.	1512.	1514.	1487.
1250.	1211.	1179.	1224.	1169.	1301.	1190.	1150.	0.	1188.	1207.	1230.	0.	1388.	1521.	1515.

0., missing data

METABOLIZABLE ENERGY,KJ/DAY-KG,75

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
1169.	1065.	1296.	0.	1587.	1613.	1331.	1102.	1302.	1237.	1196.	1222.	1468.	1193.	1666.	1218.
1184.	1211.	1194.	1219.	1507.	1373.	1370.	1367.	1196.	1154.	1128.	1157.	0.	1040.	1302.	1161.
1187.	1176.	0.	1171.	1166.	1161.	1122.	1421.	1233.	1204.	1116.	1217.	0.	1204.	1270.	1202.
1220.	1194.	1179.	1210.	1292.	1321.	1350.	1273.	1178.	1183.	1180.	1182.	0.	1300.	1489.	1437.

0., missing data

Appendix B3

FECES, GM/SUB-PERIOD (Partially dried)

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
-99.	-99.	-99.	-99.	-99.	-99.	-99.	-99.	-99.	-99.	-99.	-99.	-99.	-99.	-99.	-99.
-99.	2141.	-99.	-99.	-99.	-99.	-99.	3747.	-99.	-99.	-99.	1483.	2817.	-99.	-99.	-99.
2812.	-99.	1941.	-99.	3084.	3973.	4246.	4155.	1814.	2576.	2608.	2214.	-99.	3284.	2540.	2957.
1197.	1520.	1460.	1270.	1923.	2232.	1840.	2341.	2130.	2050.	2068.	2322.	-99.	1923.	2722.	2141.
1724.	1800.	1923.	1343.	2250.	2086.	2480.	3139.	1869.	2068.	1340.	1970.	-99.	1415.	2703.	2685.
2141.	2050.	1860.	1542.	1868.	1760.	2812.	3647.	2120.	2268.	2232.	2431.	-99.	1720.	2341.	-99.
2130.	2364.	2010.	1887.	1972.	2428.	2808.	3260.	1660.	1860.	1656.	1648.	-99.	1720.	1090.	2310.
1884.	2172.	-99.	2212.	1956.	2028.	1412.	3430.	1780.	1996.	1444.	2424.	-99.	1220.	650.	1820.
2390.	2250.	-99.	2025.	1990.	1100.	3000.	3620.	2275.	2225.	1900.	2375.	-99.	1965.	1870.	2490.
1560.	1735.	-99.	1770.	2280.	2380.	2625.	3320.	2405.	2325.	2185.	2820.	-99.	2260.	2970.	2940.
1955.	2355.	-99.	1860.	2400.	2290.	2820.	3060.	2530.	2255.	2300.	2770.	-99.	2455.	3150.	3390.
2374.	2540.	1895.	2310.	2530.	2400.	2840.	2990.	-99.	2470.	2410.	2790.	-99.	3090.	3300.	3530.

-99., missing data

DRY MATTER FRACTION OF FECES

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.918	0.0	0.0	0.0	0.0	0.0	0.863	0.0	0.0	0.0	0.878	0.907	0.0	0.0	0.0
0.970	0.0	0.910	0.0	0.971	0.874	0.950	0.864	0.950	0.967	0.937	0.848	0.0	0.850	0.907	0.962
0.972	1.000	1.000	0.973	0.975	0.880	1.000	0.875	1.000	0.924	0.966	0.959	0.0	0.964	0.953	0.846
0.927	1.000	0.860	0.934	0.918	0.887	1.000	0.887	0.953	0.951	1.000	1.000	0.0	0.937	0.914	0.959
0.942	0.951	1.000	0.950	0.936	0.888	0.896	0.888	1.000	0.958	0.940	0.949	0.0	1.000	0.957	0.0
1.000	0.910	1.000	0.921	0.922	0.868	0.932	0.868	1.000	0.941	0.948	0.949	0.0	1.000	1.000	1.000
0.945	0.930	0.0	0.965	0.958	0.867	0.951	0.867	1.000	0.950	0.955	0.943	0.0	0.950	1.000	0.948
0.906	0.914	0.0	0.932	1.000	1.000	0.932	0.859	0.916	0.943	0.944	0.933	0.0	0.931	0.929	0.927
0.936	0.949	0.0	0.928	1.000	1.000	0.910	0.858	0.927	0.923	0.935	0.935	0.0	0.906	0.937	0.931
0.960	0.954	0.0	0.954	0.956	0.874	0.951	0.874	0.946	0.967	0.949	0.970	0.0	0.963	0.960	0.970
0.958	0.965	0.947	0.944	0.939	0.872	0.955	0.872	0.0	0.950	0.940	0.938	0.0	0.930	0.913	0.944

0.0, missing data

FECAL DRY MATTER,GM/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	393.	0.	0.	0.	0.	0.	647.	0.	0.	0.	260.	511.	0.	0.	0.
303.	0.	252.	0.	428.	386.	448.	718.	287.	311.	305.	375.	0.	349.	288.	356.
233.	304.	292.	247.	375.	393.	368.	410.	426.	379.	400.	445.	0.	371.	519.	362.
320.	360.	331.	251.	413.	370.	496.	557.	356.	393.	268.	394.	0.	265.	494.	515.
403.	390.	372.	293.	350.	313.	504.	648.	424.	435.	420.	461.	0.	344.	448.	0.
426.	430.	402.	348.	364.	422.	523.	566.	332.	350.	314.	313.	0.	344.	218.	462.
356.	404.	0.	427.	375.	352.	269.	595.	356.	379.	276.	457.	0.	232.	130.	345.
433.	411.	0.	377.	398.	220.	559.	622.	417.	420.	359.	443.	0.	366.	347.	462.
292.	329.	0.	329.	456.	476.	478.	570.	446.	429.	409.	527.	0.	410.	557.	547.
375.	449.	0.	355.	459.	400.	536.	535.	479.	436.	437.	537.	0.	473.	605.	658.
455.	490.	359.	436.	475.	419.	542.	521.	0.	469.	453.	523.	0.	575.	603.	666.

0., missing data

Appendix B3

GROSS ENERGY IN FECES, CAL/GM

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	4081.	0.	0.	0.	0.	0.	4198.	0.	0.	0.	3788.	4109.	0.	0.	0.
4262.	0.	3710.	0.	4230.	4067.	4036.	4138.	3867.	4047.	4126.	3650.	0.	3699.	4165.	4223.
4145.	0.	0.	4118.	4261.	4058.	0.	4491.	0.	4268.	4280.	4407.	0.	4479.	4385.	3873.
4089.	0.	4011.	4031.	4194.	4297.	0.	4373.	4312.	4275.	0.	0.	0.	4386.	4185.	4309.
4088.	4199.	0.	4097.	4249.	3807.	4055.	4060.	0.	4251.	4215.	4244.	0.	0.	4198.	0.
0.	4193.	0.	4144.	4270.	4253.	4304.	4298.	0.	4198.	4160.	4183.	0.	0.	0.	0.
4406.	4346.	0.	4357.	4361.	4451.	4443.	4471.	0.	4310.	4281.	4231.	0.	0.	0.	4184.
4320.	4387.	0.	4391.	0.	0.	4403.	4448.	4312.	4343.	4369.	4301.	0.	4311.	4364.	4446.
4346.	4402.	0.	4100.	0.	0.	4354.	4317.	4353.	4323.	4378.	4343.	0.	4386.	4419.	4466.
4315.	4372.	0.	4156.	4462.	4416.	4408.	4469.	4372.	4397.	4391.	4465.	0.	4482.	4414.	4522.
4283.	4454.	4274.	4337.	4392.	4222.	4420.	4387.	0.	4394.	4374.	4249.	0.	4351.	4329.	4386.

0., missing data

FECAL ENERGY,KJ/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	7304.	0.	0.	0.	0.	0.	13150.	0.	0.	0.	4696.	9677.	0.	0.	0.
5566.	0.	4300.	0.	7790.	7505.	7959.	14374.	4887.	5447.	5622.	6756.	0.	6347.	5528.	6525.
4148.	0.	0.	4372.	6850.	7572.	0.	8789.	0.	7314.	7399.	8555.	0.	7201.	9978.	6932.
5893.	0.	6448.	4526.	7889.	7494.	0.	11476.	6737.	7391.	0.	0.	0.	5188.	9457.	9672.
7317.	7196.	0.	5281.	6635.	5601.	9533.	12379.	0.	8060.	7865.	8625.	0.	0.	8216.	0.
0.	8287.	0.	6537.	7039.	8633.	10104.	11714.	0.	6528.	5759.	5763.	0.	0.	0.	0.
6940.	7891.	0.	8057.	7131.	7546.	5245.	12821.	0.	7192.	5168.	8574.	0.	0.	0.	6366.
8632.	8252.	0.	7434.	0.	0.	11043.	13461.	8201.	8078.	6940.	8540.	0.	7082.	6822.	9255.
5668.	6385.	0.	6067.	0.	0.	9555.	11982.	8752.	8403.	7997.	10239.	0.	8287.	10972.	10977.
7052.	8608.	0.	6462.	8953.	8454.	10392.	11432.	9247.	8289.	8443.	10340.	0.	9199.	11624.	12816.
8500.	9458.	6771.	8375.	9289.	8471.	10494.	10966.	0.	9073.	8813.	9911.	0.	11240.	11943.	12943.

0. missing data

Appendix B3

URINE, LITRES/SUBPERIOD

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
-99,00	-99,00	-99,00	-99,00	-99,00	-99,00	-99,00	-99,00	-99,00	-99,00	-99,00	-99,00	-99,00	-99,00	-99,00	-99,00
15,30	12,20	4,30	-99,00	5.60	22,80	6,20	5,50	4,60	42,70	32,10	13,70	21,40	7,20	36,10	11,70
25,50	-99,00	8,50	-99,00	13,40	27,20	8,60	6,50	19,80	100,00	99,60	12,80	-99,00	14,10	55,10	19,70
58,00	-99,00	-99,00	18,00	15.20	31,50	-99,00	6,30	-99,00	41,80	29,90	8,50	-99,00	6,60	24,70	25,10
45,60	-99,00	20,50	17,50	12.00	21,70	-99,00	11,00	24,60	31,80	-99,00	-99,00	-99,00	17,90	27,70	21,50
46,10	18,60	-99,00	21,20	14,00	33,00	32,30	15,90	-99,00	36,40	36,10	20,90	-99,00	-99,00	31,40	-99,00
-99,00	25,30	-99,00	23,50	10,40	23,80	27,00	11,90	-99,00	57,80	51,40	9,30	-99,00	-99,00	-99,00	-99,00
13,20	21,90	-99,00	13,90	8,70	19,60	23,90	10,30	-99,00	41,30	27,60	12,00	-99,00	-99,00	-99,00	10,80
37,20	14,60	-99,00	14,80	-99,00	-99,00	22,10	12,10	14,60	48,60	48,30	17,10	-99,00	10,70	28,10	13,70
54,30	16,30	-99,00	73,00	-99,00	-99,00	32,20	12,00	11,40	20,50	11,60	15,20	-99,00	10,20	31,60	11,40
79,50	15,30	-99,00	86,70	10,00	15,80	28,20	10,80	7,80	16,10	9,10	15,10	-99,00	17,30	35,30	13,20
67,40	18,50	22,40	49,80	12,10	18,70	29,00	11,60	-99,00	13,00	8,30	10,70	-99,00	12,80	37,40	14,10

-99., missing data

URINE ENERGY,KJ/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	1126.	0.	0.	0.	0.	0.	579.	0.	0.	0.	937.	1319.	0.	0.	0.
1073.	0.	710.	0.	1057.	1539.	882.	639.	1094.	1101.	1169.	890.	0.	1041.	1538.	791.
1069.	0.	0.	1032.	1081.	1510.	0.	708.	0.	1041.	969.	715.	0.	743.	1184.	1008.
827.	0.	646.	983.	1096.	887.	0.	819.	793.	1296.	0.	0.	0.	742.	1400.	870.
770.	865.	0.	1230.	1195.	879.	1060.	1081.	0.	1179.	1144.	1008.	0.	0.	1284.	0.
0.	987.	0.	1167.	952.	1265.	1159.	1249.	0.	949.	851.	1014.	0.	0.	0.	0.
863.	1293.	0.	1241.	1239.	1276.	1139.	1497.	0.	1362.	938.	1220.	0.	0.	0.	787.
996.	1024.	0.	1061.	0.	0.	1060.	1507.	1055.	1162.	918.	1150.	0.	800.	898.	888.
1149.	1235.	0.	1335.	0.	0.	1655.	1797.	1348.	1668.	1036.	1239.	0.	924.	1465.	1280.
1317.	1260.	0.	1448.	1308.	1208.	1592.	1603.	1197.	1734.	1004.	1337.	0.	1480.	1571.	1456.
1349.	1425.	1161.	1628.	1526.	1446.	1875.	1817.	0.	1975.	1008.	1131.	0.	1585.	1756.	1637.

0., missing data

APPENDIX B4. RECORDED LIVEWEIGHT (lbs) FOR EACH PIG.

Date		Pig No. 11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28	
May	23	64	75	68		51	61	73	82	73	74	60	82	68	67	65	59	adjustment program
	24	64	74	69		51	61	73	83	69	73	60	79	68	66	63	60	
	26	65	75	71		56	65	76	86	75	78	62	81	70	70	69	64	
	28	66	77	73		59	68	80	90	76	77	66	84	73	69	70	65	
	30	68	81	75		62	71	84	95	82	79	67	87	77	76	74	69	
June	1	71	81	77		63	73	85	99	82	83	68	90	80	78	76	72	
	3	74	84	80		67	77	88	99	85	87	70	94	85	82	80	73	
	5	77	89	85		69	80	90	102	88	90	73	97	88	84	83	77	
	7	79	92	87		72	82	89	105	91	90	76	99	91	88	85	79	
	9	83	94	90		74	86	95	110	93	94	74	104	93	91	88	82	
	11	84	96	91		75	90	98	113	96	94	78	106	96	93	92	85	
	13	86	97	94		76	93	103	117	97	95	85	110	99	94	91	87	
	15	89	101	96		78	97	106	121	101	106	82	112	104	97	98	92	experimental program
	17	90	101	98		80	99	107	119	102	106	86	115	104	100	100	96	
	19	93	103	101		83	104	108	122	108	106	90	119	111	105	106	100	
	21	94	105	102		86	105	111	123	107	108	96	119	114	108	107	100	
	23	95	107	102		88	109	115	125	116	113	100	127	118	112	111	106	
	*25	97	109	104		90	112	118	128	120	116	104	130	121	115	115	109	
	27	97	110	106	94	96	113	119	132	121	122	104	133	116	118	118	103	
	*29	98	112	107	95	100	116	122	136	128	128	108	137		121	121	108	
	30	102	113	110	95	102	119	124	136	128	127	108	137		123	128	109	
July	3	111	118	113	103	108	115	124	143	123	126	106	138		123	129	111	
	*5	113	122	115	106	112	120	126	146	124	127	107	139		124	130	112	
	6	116	123	121	109	112	127	130	145	127	128	111	138		120	128	114	
	8	120	127	122	111	115	131	135	153	128	130	110	143		125	129	117	
	10	123	131	126	114	118	132	139	157	130	133	112	147		126	134	116	
	12	125	135	128	120	121	132	145	159	133	134	116	149		124	139	120	
	*14	128	139	131	122	124	136	148	162	135	137	120	153		130	142	122	
	15	131	141	132	123	125	139	150	170	136	137	121	153		130	140	125	
	17	127	139	132	124	120	141	153	167	138	141	126	161		135	131	129	
	19	128	139	134	123	124	141	154	167	142	145	128	164		133	134	133	
	21	130	140	136	125	127	144	157	175	144	146	130	170		134	130	136	
	23	133	140	137	128	130	143	156	177	148	150	130	171		136	129	138	
	25	136	143		130	131	143	150	176	151	152	132	175		138	133	142	
	27	136	144		130	133	136	155	183	156	156	137	178		143	142	147	
	*29	139	145		133	136	138	160	186	159	159	140	181		145	148	151	
	30	139	148		133	136	143	164	187	159	160	145	184		150	148	152	
Aug	1	146	155		142	143	148	171	195	161	161	143	184		151	151	152	
	3	152	160		145	143	150	178	200	162	161	144	184		151	157	156	
	*5	156	165		148	146	154	183	203	163	163	145	186		154	160	158	
	7	162	170	125	154	155	161	185	209	164	163	147	188		155	164	160	
	9	169	173	130	155	158	163	187	210	167	165	150	191		158	168	160	
	11	165	173	133	160	165	173	193	213	163	167	152	192		161	170	165	
	*13	172	177	136	162	170	176	197	216		170	154	195		164	173	168	
	14	168	176	140	160	168	176	200	217		171	157	197		165	177	170	

* estimated weights used for calculating amount of feed.

Appendix B5

PERIOD AVERAGE DAILY GAIN,GM/DAY(CALCULATED OVER SUB-PERIODS 2 AND 3

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
361.	393.	419.	-99.	727.	649.	560.	679.	839.	646.	796.	848.	794.	790.	872.	507.
725.	907.	578.	758.	658.	528.	1024.	1164.	476.	363.	381.	734.	-99.	400.	688.	526.
429.	418.	-99.	370.	433.	-99.	396.	626.	775.	699.	783.	729.	-99.	816.	1002.	924.
539.	508.	950.	602.	1017.	1093.	907.	649.	442.	453.	547.	547.	-99.	602.	798.	587.

-99., missing data

Appendix B6

PERIOD AVERAGE WEIGHT,KG,CALCULATED OVER SUB/PERIODS 2 AND 3

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
44.1	49.3	47.6	-99.0	39.7	48.3	51.3	58.5	53.5	53.3	46.3	59.8	51.7	52.3	52.6	47.4
55.8	59.6	57.1	52.3	53.6	60.0	63.4	71.1	59.3	59.9	50.8	66.2	-99.0	56.7	60.8	53.7
61.1	64.9	-99.0	58.6	59.6	64.9	72.1	81.5	68.8	69.3	61.1	79.7	-99.0	63.6	61.8	64.7
74.4	77.7	59.9	70.4	71.8	74.7	85.7	95.3	74.5	75.0	68.1	86.5	-99.0	71.8	76.0	73.7

-99., missing data

Appendix B7

PROTEIN FRACTION OF FECES

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.1943	0.0	0.0	0.0	0.0	0.0	0.2089	0.0	0.0	0.0	0.1621	0.2039	0.0	0.0	0.0
0.2057	0.0	0.1593	0.0	0.1981	0.1741	0.2272	0.2027	0.1895	0.1655	0.2056	0.1588	0.0	0.1703	0.1662	0.2003
0.1642	0.0	0.0	0.1615	0.1837	0.1708	0.0	0.2155	0.0	0.1999	0.2044	0.1937	0.0	0.2072	0.2158	0.2256
0.1894	0.0	0.2084	0.1642	0.1890	0.1908	0.0	0.2223	0.1978	0.1946	0.0	0.0	0.0	0.1993	0.2151	0.2126
0.1898	0.1861	0.0	0.1524	0.1941	0.1787	0.1897	0.2110	0.0	0.1974	0.2121	0.1892	0.0	0.0	0.2000	0.0
0.0	0.1938	0.0	0.1607	0.2145	0.2033	0.2137	0.2263	0.0	0.1797	0.1815	0.1727	0.0	0.0	0.0	0.0
0.2056	0.1884	0.0	0.1755	0.1972	0.2084	0.2095	0.2268	0.0	0.1504	0.1699	0.1469	0.0	0.0	0.0	0.1669
0.1851	0.2050	0.0	0.1945	0.0	0.0	0.2025	0.2255	0.1887	0.1748	0.1693	0.1679	0.0	0.1783	0.1868	0.2027
0.1825	0.1959	0.0	0.1643	0.0	0.0	0.2110	0.2133	0.2052	0.1911	0.2019	0.1866	0.0	0.2087	0.2064	0.2268
0.1440	0.1806	0.0	0.1519	0.1854	0.1776	0.1895	0.2035	0.1918	0.1667	0.1814	0.1899	0.0	0.1978	0.1912	0.2100
0.1474	0.1889	0.1973	0.1637	0.1777	0.1566	0.1860	0.1999	0.0	0.1940	0.2015	0.1911	0.0	0.2035	0.1983	0.2241

0.0, missing data

FECAL PROTEIN,GM/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	83.	0.	0.	0.	0.	0.	157.	0.	0.	0.	48.	115.	0.	0.	0.
64.	0.	44.	0.	87.	77.	107.	168.	57.	53.	67.	70.	0.	70.	53.	74.
39.	0.	0.	41.	71.	76.	0.	101.	0.	82.	85.	90.	0.	80.	117.	97.
65.	0.	80.	44.	85.	80.	0.	140.	74.	80.	0.	0.	0.	56.	116.	114.
81.	76.	0.	47.	73.	63.	107.	154.	0.	90.	95.	92.	0.	0.	94.	0.
0.	92.	0.	61.	85.	99.	120.	148.	0.	67.	60.	57.	0.	0.	0.	0.
77.	82.	0.	78.	77.	85.	59.	156.	0.	60.	49.	71.	0.	0.	0.	61.
88.	92.	0.	79.	0.	0.	121.	163.	86.	78.	64.	80.	0.	70.	70.	101.
37.	68.	0.	58.	0.	0.	111.	142.	99.	89.	88.	105.	0.	94.	123.	133.
56.	85.	0.	57.	69.	81.	107.	125.	97.	75.	83.	105.	0.	97.	120.	142.
70.	96.	75.	76.	90.	75.	106.	120.	0.	96.	97.	107.	0.	126.	131.	158.

0., missing data

Appendix B7

URINE PROTEIN, PERCENT

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.00	6.41	5.08	0.0	5.55	3.70	7.30	7.31	3.77	1.03	1.10	4.75	4.28	4.81	1.85	3.29
2.66	0.0	5.55	0.0	5.35	3.97	7.55	6.83	3.73	0.78	0.95	4.83	0.0	5.75	1.89	2.51
1.28	0.0	0.0	3.98	4.94	3.33	0.0	7.80	0.0	1.73	2.25	5.84	0.0	7.82	3.33	2.79
1.26	0.0	2.19	3.90	6.34	2.84	0.0	5.17	2.24	2.83	0.0	0.0	0.0	2.88	3.51	2.81
1.16	3.23	0.0	4.03	5.93	1.85	2.28	4.72	0.0	2.25	2.20	3.35	0.0	0.0	2.84	0.0
0.0	2.71	0.0	3.45	6.36	3.69	2.98	7.29	0.0	1.14	1.15	7.57	0.0	0.0	0.0	0.0
4.54	4.10	0.0	6.20	9.89	4.52	3.31	10.09	0.0	2.29	2.36	7.06	0.0	0.0	0.0	5.06
1.86	4.87	0.0	4.98	0.0	0.0	3.33	8.65	5.02	1.66	1.32	4.67	0.0	5.19	2.22	4.50
1.47	5.26	0.0	1.27	0.0	0.0	3.57	10.40	8.21	5.65	6.20	5.66	0.0	6.29	3.22	7.80
1.15	5.72	0.0	1.16	9.08	5.31	3.92	10.31	10.66	7.48	7.66	6.15	0.0	5.94	3.09	7.66
1.39	5.35	3.60	2.27	8.76	5.37	4.49	10.88	0.0	10.55	8.43	7.34	0.0	8.60	3.26	8.06

0.0, missing data

URINE PROTEIN,GM/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	156.	0.	0.	0.	0.	0.	80.	0.	0.	0.	130.	183.	0.	0.	0.
149.	0.	99.	0.	147.	214.	122.	89.	152.	153.	162.	124.	0.	145.	214.	110.
148.	0.	0.	143.	150.	210.	0.	98.	0.	145.	135.	99.	0.	103.	165.	140.
115.	0.	90.	136.	152.	123.	0.	114.	110.	180.	0.	0.	0.	103.	194.	121.
107.	120.	0.	171.	166.	122.	147.	150.	0.	164.	159.	140.	0.	0.	178.	0.
0.	137.	0.	162.	132.	176.	161.	174.	0.	132.	118.	141.	0.	0.	0.	0.
120.	180.	0.	172.	172.	177.	158.	208.	0.	189.	130.	169.	0.	0.	0.	109.
138.	142.	0.	147.	0.	0.	147.	209.	147.	161.	128.	160.	0.	111.	125.	123.
160.	171.	0.	165.	0.	0.	230.	250.	187.	232.	144.	172.	0.	128.	204.	178.
183.	175.	0.	201.	182.	168.	221.	223.	166.	241.	139.	186.	0.	206.	218.	202.
187.	198.	161.	226.	212.	201.	260.	252.	0.	274.	140.	157.	0.	220.	244.	227.

0., missing data

PROTEIN BALANCE,GM/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	58.	0.	0.	0.	0.	0.	107.	0.	0.	0.	144.	115.	0.	0.	0.
57.	0.	144.	0.	107.	101.	109.	71.	47.	80.	54.	67.	0.	86.	123.	114.
93.	0.	0.	81.	142.	110.	0.	96.	0.	13.	65.	68.	0.	48.	16.	71.
135.	0.	151.	129.	177.	126.	0.	185.	137.	64.	0.	0.	0.	81.	80.	102.
185.	197.	0.	99.	133.	254.	225.	267.	0.	141.	58.	194.	0.	0.	131.	0.
0.	142.	0.	115.	133.	121.	153.	208.	0.	173.	161.	209.	0.	0.	0.	0.
163.	117.	0.	100.	94.	92.	33.	164.	0.	144.	93.	196.	0.	0.	0.	159.
139.	146.	0.	128.	0.	0.	222.	216.	169.	163.	172.	206.	0.	182.	176.	201.
169.	164.	0.	131.	0.	0.	222.	197.	131.	97.	153.	186.	0.	133.	192.	163.
131.	125.	0.	99.	152.	161.	142.	142.	117.	63.	125.	129.	0.	147.	150.	140.
172.	146.	108.	109.	108.	168.	108.	122.	0.	57.	160.	211.	0.	140.	171.	159.

0., missing data

Appendix B7

PROTEIN BALANCE,KJ/DAY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	1353.	0.	0.	0.	0.	0.	2519.	0.	0.	0.	3376.	2712.	0.	0.	0.
1350.	0.	3383.	0.	2522.	2382.	2572.	1662.	1115.	1874.	1265.	1565.	0.	2027.	2892.	2673.
2177.	0.	0.	1902.	3326.	2594.	0.	2268.	0.	304.	1518.	1596.	0.	1125.	370.	1667.
3163.	0.	3556.	3032.	4162.	2950.	0.	4349.	3224.	1510.	0.	0.	0.	1897.	1888.	2409.
4350.	4641.	0.	2332.	3125.	5971.	5285.	6283.	0.	3312.	1359.	4569.	0.	0.	3086.	0.
0.	3338.	0.	2703.	3129.	2855.	3599.	4895.	0.	4069.	3795.	4919.	0.	0.	0.	0.
3822.	2758.	0.	2339.	2207.	2166.	781.	3863.	0.	3385.	2181.	4614.	0.	0.	0.	3735.
3272.	3428.	0.	3008.	0.	0.	5214.	5074.	3981.	3839.	4048.	4835.	0.	4276.	4138.	4733.
3974.	3854.	0.	3088.	0.	0.	5212.	4622.	3085.	2287.	3602.	4364.	0.	3123.	4508.	3828.
3082.	2936.	0.	2322.	3580.	3780.	3334.	3348.	2746.	1487.	2927.	3024.	0.	3449.	3529.	3283.
4031.	3429.	2540.	2559.	2531.	3944.	2538.	2875.	0.	1333.	3758.	4951.	0.	3292.	4020.	3728.

0, missing data

PROTEIN RETENTION,KJ/DAY-KG.75

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	73.	0.	0.	0.	0.	0.	119.	0.	0.	0.	157.	141.	0.	0.	0.
79.	0.	187.	0.	159.	130.	134.	79.	56.	95.	71.	73.	0.	104.	148.	148.
107.	0.	0.	98.	168.	119.	0.	93.	0.	14.	80.	69.	0.	54.	17.	84.
155.	0.	171.	156.	210.	137.	0.	178.	151.	70.	0.	0.	0.	92.	87.	121.
213.	216.	0.	120.	158.	277.	235.	257.	0.	154.	71.	197.	0.	0.	142.	0.
0.	146.	0.	128.	146.	125.	145.	180.	0.	169.	174.	184.	0.	0.	0.	0.
175.	121.	0.	110.	103.	95.	32.	142.	0.	141.	100.	173.	0.	0.	0.	164.
150.	150.	0.	142.	0.	0.	211.	187.	167.	160.	185.	181.	0.	190.	188.	207.
157.	147.	0.	127.	0.	0.	185.	152.	122.	90.	152.	154.	0.	127.	175.	152.
122.	112.	0.	96.	145.	149.	118.	110.	108.	58.	123.	107.	0.	140.	137.	131.
159.	131.	118.	105.	103.	155.	90.	94.	0.	52.	159.	175.	0.	133.	156.	148.

0, missing data

PROTEIN RETENTION,KJ/DAY-KG.75 (Period Means)

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
79.	73.	187.	0.	159.	130.	134.	99.	56.	95.	71.	115.	141.	104.	148.	148.
158.	216.	171.	125.	179.	178.	235.	176.	151.	79.	76.	133.	0.	73.	82.	103.
162.	139.	0.	127.	124.	110.	129.	170.	167.	157.	153.	180.	0.	190.	188.	186.
146.	130.	118.	109.	124.	152.	131.	119.	115.	67.	145.	145.	0.	133.	156.	144.

0., missing data

Appendix B8

PROTEIN GAIN/TOTAL DAILY GAIN

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.146	0.0	0.0	0.0	0.0	0.0	0.158	0.0	0.0	0.0	0.169	0.145	0.0	0.0	0.0
0.159	0.0	0.344	0.0	0.148	0.156	0.195	0.104	0.057	0.123	0.068	0.079	0.0	0.109	0.141	0.224
0.128	0.0	0.0	0.107	0.215	0.207	0.0	0.083	0.0	0.036	0.169	0.093	0.0	0.120	0.023	0.135
0.186	0.0	0.262	0.170	0.269	0.238	0.0	0.159	0.288	0.177	0.0	0.0	0.0	0.202	0.117	0.195
0.255	0.218	0.0	0.131	0.202	0.481	0.220	0.230	0.0	0.388	0.152	0.265	0.0	0.0	0.191	0.0
0.0	0.340	0.0	0.311	0.308	-1.227	0.387	0.333	0.0	0.248	0.206	0.287	0.0	0.0	0.0	0.0
0.379	0.281	0.0	0.269	0.217	-0.931	0.084	0.263	0.0	0.206	0.119	0.269	0.0	0.0	0.0	0.172
0.325	0.349	0.0	0.346	0.0	0.0	0.560	0.345	0.219	0.234	0.220	0.282	0.0	0.223	0.176	0.218
0.314	0.323	0.0	0.218	0.0	0.0	0.245	0.303	0.297	0.215	0.280	0.340	0.0	0.221	0.240	0.277
0.243	0.246	0.0	0.164	0.150	0.147	0.156	0.220	0.264	0.140	0.228	0.235	0.0	0.244	0.188	0.238
0.318	0.287	0.114	0.181	0.106	0.153	0.119	0.189	0.0	0.125	0.292	0.385	0.0	0.233	0.214	0.270

0.0, missing data

PROTEIN GAIN/TOTAL DAILY GAIN

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.159	0.146	0.344	0.0	0.148	0.156	0.195	0.131	0.057	0.123	0.068	0.124	0.145	0.109	0.141	0.224
0.190	0.218	0.262	0.136	0.229	0.309	0.220	0.157	0.288	0.200	0.161	0.179	0.0	0.161	0.110	0.165
0.352	0.323	0.0	0.309	0.262	-1.079	0.344	0.313	0.219	0.229	0.182	0.280	0.0	0.223	0.176	0.195
0.292	0.285	0.114	0.188	0.128	0.150	0.173	0.237	0.281	0.160	0.267	0.320	0.0	0.232	0.214	0.262

0.0, missing data

Appendix B9

DRY MATTER DIGESTIBILITY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	75.1	0.0	0.0	0.0	0.0	0.0	63.7	0.0	0.0	0.0	85.2	76.7	0.0	0.0	0.0
79.5	0.0	84.0	0.0	77.2	82.0	76.4	69.5	83.5	81.8	80.3	79.9	0.0	79.4	86.8	78.1
85.5	0.0	0.0	83.7	81.9	82.6	0.0	81.9	0.0	79.3	75.4	77.3	0.0	79.0	77.2	79.4
81.7	0.0	81.5	84.9	81.4	80.5	0.0	78.0	80.8	79.0	0.0	0.0	0.0	80.9	78.1	71.5
78.0	79.9	0.0	83.4	83.0	85.5	78.6	76.9	0.0	77.6	75.7	78.0	0.0	0.0	77.4	0.0
0.0	78.0	0.0	80.5	80.3	79.8	77.1	79.7	0.0	82.1	82.5	85.4	0.0	0.0	0.0	0.0
80.8	79.3	0.0	76.3	78.8	80.7	79.2	78.1	0.0	81.3	80.3	79.7	0.0	0.0	0.0	79.7
77.2	79.2	0.0	79.5	0.0	0.0	78.0	79.6	80.0	79.9	81.0	80.8	0.0	80.6	81.9	79.1
85.2	84.1	0.0	82.9	0.0	0.0	83.4	81.1	79.1	80.0	79.3	77.8	0.0	77.5	79.0	77.5
82.6	79.9	0.0	82.9	81.3	83.2	80.4	81.2	78.3	80.2	78.4	78.0	0.0	81.9	78.7	76.6
79.8	78.8	80.1	79.8	77.9	82.0	78.2	79.9	0.0	79.1	78.3	79.0	0.0	77.5	79.0	76.7

0.0, missing data

DRY MATTER DIGESTIBILITY (Period Means)

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
79.5	75.1	84.0	0.0	77.2	82.0	76.4	66.6	83.5	81.8	80.3	82.6	76.7	79.4	86.8	78.1
81.7	79.9	81.5	84.0	82.1	82.9	78.6	78.9	80.8	78.6	75.6	77.7	0.0	79.9	77.6	75.5
79.0	78.8	0.0	78.7	79.5	80.3	78.1	79.2	80.0	81.1	81.3	82.0	0.0	80.6	81.9	79.4
82.5	80.9	80.1	81.8	79.6	82.6	80.7	80.7	78.7	79.7	78.7	78.2	0.0	79.0	78.9	76.9

0.0, missing data

ENERGY DIGESTIBILITY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	74.1	0.0	0.0	0.0	0.0	0.0	59.3	0.0	0.0	0.0	85.2	75.4	0.0	0.0	0.0
79.1	0.0	84.9	0.0	77.1	80.6	76.8	66.6	84.6	82.4	79.9	80.2	0.0	79.3	86.0	77.8
85.7	0.0	0.0	84.1	81.8	81.5	0.0	78.6	0.0	78.1	74.8	76.1	0.0	77.6	75.9	78.2
81.1	0.0	79.8	84.9	80.4	77.8	0.0	74.6	79.6	77.9	0.0	0.0	0.0	79.0	76.5	70.4
77.3	78.9	0.0	83.0	81.8	85.2	77.0	74.9	0.0	76.3	74.6	76.6	0.0	0.0	76.4	0.0
0.0	76.9	0.0	80.0	79.2	77.5	76.0	77.2	0.0	81.9	82.5	85.4	0.0	0.0	0.0	0.0
79.6	78.0	0.0	75.6	78.0	77.5	77.9	74.3	0.0	80.7	79.9	79.3	0.0	0.0	0.0	79.5
75.5	77.5	0.0	78.2	0.0	0.0	76.6	76.3	78.8	79.2	80.2	80.1	0.0	79.8	80.9	77.4
84.6	83.4	0.0	83.0	0.0	0.0	82.2	78.6	78.0	78.9	78.2	76.8	0.0	75.5	77.8	75.7
82.2	79.1	0.0	83.0	80.2	80.7	79.3	78.1	77.2	79.5	77.2	76.9	0.0	80.8	77.7	75.2
79.5	77.8	79.7	78.9	76.6	80.3	77.1	77.1	0.0	78.0	77.1	78.4	0.0	76.1	77.4	75.4

0.0, missing data

(Period means on next page)

Appendix B9

ENERGY DIGESTIBILITY (Period means)

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
79,1	74.1	84,9	0.0	77,1	80.6	76,8	63,0	84,6	82,4	79,9	82,7	75,4	79,3	86,0	77,8
81,4	78.9	79,8	84.0	81,3	81.5	77,0	76,0	79,6	77,4	74,7	76,3	0,0	78,3	76,3	74,3
77,6	77.5	0,0	78.0	78,6	77,5	76,8	75,9	78,8	80,6	80,9	81,6	0,0	79,8	80,9	78,5
82,1	80.1	79,7	81.7	78,4	80,5	79,5	77,9	77,6	78,8	77,5	77,4	0,0	77,5	77,6	75,4

0.0, missing data

PROTEIN DIGESTIBILITY

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
0,0	0.0	0,0	0.0	0,0	0.0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,0	72.0	0,0	0.0	0,0	0,0	0,0	54,5	0,0	0,0	0,0	85,1	72,2	0,0	0,0	0,0
76,3	0.0	84,6	0.0	74,4	80,4	68,4	48,6	77,7	81.4	76,3	73,0	0,0	76,8	86,5	75,1
86,0	0.0	0,0	84.5	80,5	80,7	0,0	65,9	0,0	65,8	70,2	65,0	0,0	65,5	60,5	68,6
79,3	0.0	75,1	85.8	79,5	75,8	0,0	68,2	77,0	75,2	0,0	0,0	0,0	76,5	70,3	66,2
78,2	80.6	0,0	85.2	80,5	85,7	77,7	73,1	0,0	77,3	69,6	78,4	0,0	0,0	76,8	0,0
0,0	75.3	0,0	82.0	75,8	75,1	72,4	72,1	0,0	82,0	82,3	86,0	0,0	0,0	0,0	0,0
78,5	78.4	0,0	77.8	77,5	76,1	76,4	70,5	0,0	84,7	82,0	83,7	0,0	0,0	0,0	81,5
75,8	75.7	0,0	77,8	0,0	0,0	75,2	72,3	78,6	80,7	82,3	82,1	0,0	80,7	81,2	76,3
85,2	83.2	0,0	84,5	0,0	0,0	80,3	75,9	76,3	78,7	77,1	77,3	0,0	73,5	76,3	71,9
84,8	77.9	0,0	84,1	79,0	80,2	77,3	74,6	74,5	80,2	76,0	74,9	0,0	78,4	75,4	70,6
83,7	78.2	78,3	81.6	78,0	83,1	77,7	75,8	0,0	77,5	75,5	77,5	0,0	74,1	76,0	70,9

0.0, missing data

PROTEIN DIGESTIBILITY (Period means)

11	12	13	14	15	16	17	18	21	22	23	24	25	26	27	28
76,3	72.0	84,6	0.0	74,4	80,4	68,4	51,6	77,7	81,4	76,3	79,0	72,2	76,8	86,5	75,1
81,2	80.6	75,1	85.2	80,2	80,7	77,7	69,0	77,0	72,8	69,9	71,7	0,0	71,0	69,2	67,4
77,2	76.5	0,0	79,2	76,7	75,6	74,7	71,6	78,6	82,5	82,2	83,9	0,0	80,7	81,2	78,9
84,6	79.7	78,3	83.4	78,5	81,6	78,4	75,4	75,4	78,8	76,2	76,6	0,0	75,3	75,9	71,1

0.0, missing data

APPENDIX C

ANALYSIS OF VARIANCE

Note: Only F values significant at $P < 0.01$ have been entered in Appendix C.

APPENDIX C1. DAILY FEED INTAKE, g/kg$^{0.75}$. ANALYSIS OF VARIANCE.

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	0.8237	0.8237	
Feed (F)	1	2629.5088	2629.5088	27.0
G * F	1	11.5940	11.5940	
Hogs(H)/G*F	12	1170.1695	97.5141	
Periods (P)	3	676.9877	225.6626	
P * G	3	518.1633	172.7211	
P * F	3	458.9740	152.9913	
P * G * F	3	531.4528	177.1509	
P * H/G * F	31	1559.6519	50.3114	
Total	58	7557.3257		

APPENDIX C2. DAILY ME INTAKE, kJ/kg$^{0.75}$. ANALYSIS OF VARIANCE.

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	847.45	847.45	
Feed (F)	1	219809.76	219809.76	14.20
G * F	1	1004.74	1004.74	
Hogs(H)/G*F	12	185781.71	15481.81	
Periods (P)	3	66865.21	22288.40	
P * G	3	70811.58	23603.86	
P * F	3	45476.82	15158.94	
P * G * F	3	50844.09	16948.03	
P * H/G * F	31	314115.87	10132.77	
Total	58	955557.24		

APPENDIX C3. DAILY GAIN, g/kg$^{0.75}$. ANALYSIS OF VARIANCE.

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	21930.88	21930.88	
Feed (F)	1	219280.80	219280.80	12.86
G * F	1	16000.25	16000.25	
Hogs(H)/G*F	12	204477.88	17039.82	
Periods (P)	3	18938.03	6312.68	
P * G	3	1078708.93	359569.64	15.42
P * F	3	41940.52	13980.17	
P * G * F	3	84222.14	28074.05	
P * H/G * F	30	699494.31	23316.48	
Total	57	2384993.76		

APPENDIX C4. DAILY PROTEIN RETENTION, KJ/kg$^{0.75}$. ANALYSIS OF VARIANCE (SUBPERIODS 1 - 3 POOLED).

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	1925.631	1925.631	
Feed (F)	1	2859.181	2859.181	
G * F	1	376.275	376.275	
Hogs(H)/G*F	12	9805.852	817.154	
Periods (P)	3	14817.348	4939.116	6.39
P * G	3	25778.248	8592.749	11.12
P * F	3	3021.091	1007.030	
P * G * F	3	4209.814	1403.271	
P * H/G * F	31	23948.979	772.548	
Total	58	86742.4202		

APPENDIX C5. DAILY PROTEIN RETENTION, KJ/kg$^{0.75}$. ANALYSIS OF VARIANCE (SUBPERIODS 2 AND 3 POOLED).

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	800.460	800.460	
Feed (F)	1	2699.684	2699.684	
G * F	1	612.446	612.446	
Hogs(H)/G*F	12	12019.652	1001.638	
Periods (P)	3	20679.579	6893.193	8.12
P * G	3	23277.832	7759.277	9.14
P * F	3	2332.865	777.622	
P * G * F	3	6468.824	2156.275	
P * H/G * F	31	26312.803	848.800	
Total	57			

APPENDIX C6. RATIO OF PROTEIN GAIN TO TOTAL DAILY GAIN. ANALYSIS OF VARIANCE.

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	0.019796519	0.019796519	
Feed (F)	1	0.004320254	0.004320254	
G * F	1	0.000182653	0.000182653	
Hogs(H)/G*F	12	0.026667532	0.002222294	
Periods (P)	3	0.090776566	0.030258855	9.41
P * G	3	0.047067457	0.015689152	4.88
P * F	3	0.003913129	0.001304376	
P * G * F	3	0.017723174	0.005907725	
P * H/G * F	31	0.096385718	0.003212857	
Total	58	0.306833001		

APPENDIX C7. DRY MATTER DIGESTIBILITY, %. ANALYSIS OF VARIANCE (SUBPERIODS 2 AND 3 POOLED).

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	4.7176	4.7176	
Feed (F)	1	30.3046	30.3046	
G * F	1	0.2835	0.2835	
Hogs(H)/G*F	12	135.8619	135.8619	
Periods (P)	3	1.6934	0.5645	
P * G	3	128.9267	42.9756	8.25
P * F	3	10.1041	3.3680	
P * G * F	3	9.0415	3.0138	
P * H/G * F	31	161.5133	5.2101	
Total	58	482.4466		

APPENDIX C8. ENERGY DIGESTIBILITY, %. ANALYSIS OF VARIANCE (SUBPERIODS 2 AND 3 POOLED).

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	22.8395	22.8395	
Feed (F)	1	215.1501	215.1501	
G * F	1	4.7737	4.7737	
Hogs(H)/G*F	12	520.0743	43.3395	
Periods (P)	3	109.2151	36.4050	
P * G	3	472.2813	157.4271	11.36
P * F	3	10.6374	3.5458	
P * G * F	3	67.4214	22.4738	
P * H/G * F	31	429.5690	13.8571	
Total	58	1851.9610		

APPENDIX C9. PROTEIN DIGESTIBILITY, %. ANALYSIS OF VARIANCE (SUBPERIODS 2 AND 3 POOLED).

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	5.9846	5.9846	
Feed (F)	1	178.9420	178.9420	
G * F	1	3.7174	3.7174	
Hogs(H)/G*F	12	572.6138	47.7178	
Periods (P)	3	52.3238	17.4413	
P * G	3	328.0175	109.3392	7.70
P * F	3	14.0995	4.6998	
P * G * F	3	70.5061	23.5020	
P * H/G * F	31	441.3679	14.2377	
Total	58	1667.5727		

APPENDIX C10. TEMPORARY WEIGHT CHANGE, kg. ANALYSIS OF VARIANCE(RESTRICTED AND AD LIBITUM FED PIGS).

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	0.000407	0.000407	
Feed (F)	1	0.000036	0.000036	
G * F	1	0.0	0.0	
Hogs(H)/G*F	12	9.658688	0.804891	
Periods (P)	3	36.450757	18.225378	6.18
P * G	3	73.189599	36.594799	12.40
P * F	3	2.480443	1.240222	
P * G * F	3	12.356058	6.178029	
P * H/G * F	31	41.282411	29.948744	
Total	58	175.418392		

TEMPORARY WEIGHT CHANGE, kg. ANALYSIS OF VARIANCE(RESTRICTED-FED PIGS ONLY).

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	30.914084	30.914084	34.0
Hogs(H)/G*F	6	5.453180	0.908863	
Periods (P)	2	28.937920	14.468960	
P * G	2	86.808663	43.404332	19.20
P * H/G * F	8	20.339564	2.259952	
Total	19	172.453410		

APPENDIX C11. TEMPORARY CHANGE IN FECAL OUTPUT, kg. ANALYSIS OF VARIANCE(RESTRICTED AND AD LIBITUM-FED PIGS).

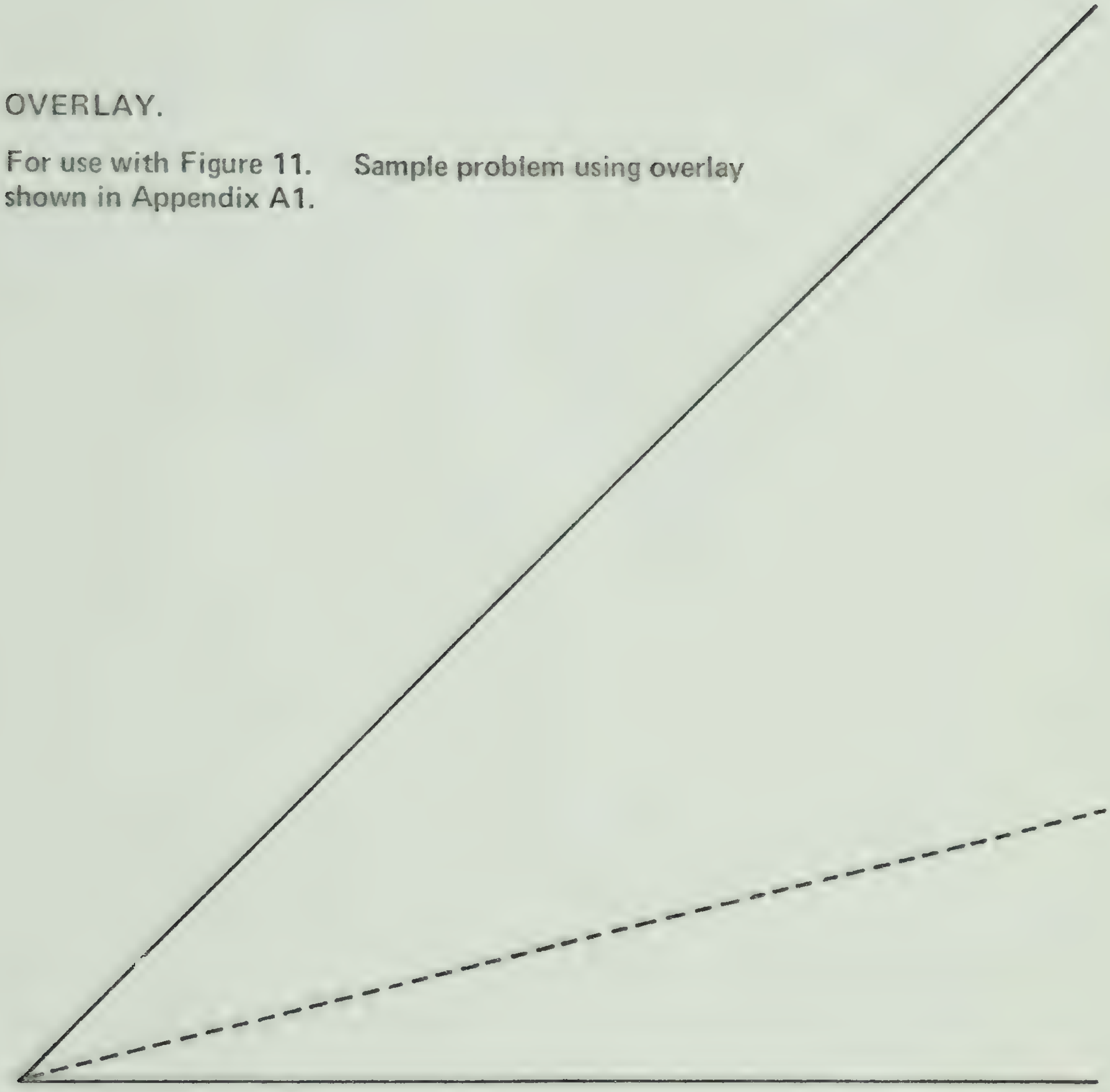
Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	0.0000568	0.0000568	
Feed (F)	1	0.0000013	0.0000013	
G * F	1	0.0000035	0.0000035	
Hogs(H)/G*F	12	21.4988398	1.7915700	
Periods (P)	3	1.0503513	0.5251756	
P * G	3	31.5848757	15.7924378	12.0
P * F	3	4.5154701	2.2577350	
P * G * F	3	1.5046077	0.7523039	
P * H/G * F	31	22.4075847	1.3180932	
Total	58	82.5617909		

TEMPORARY CHANGE IN FECAL OUTPUT, kg. ANALYSIS OF VARIANCE(RESTRICTED-FED PIGS ONLY).

Source of Variation	d.f.	Sums of Squares	Mean Square	Fcalc
Group (G)	1	2.9400746	2.9400746	
Hogs(H)/G*F	6	5.5812417	0.9302069	
Periods (P)	2	6.8862806	3.4431403	
P * G	2	31.4756064	15.7378032	23.1
P * H/G * F	8	5.4408613	0.6801077	
Total	19	52.3240645		

OVERLAY.

For use with Figure 11. Sample problem using overlay shown in Appendix A1.



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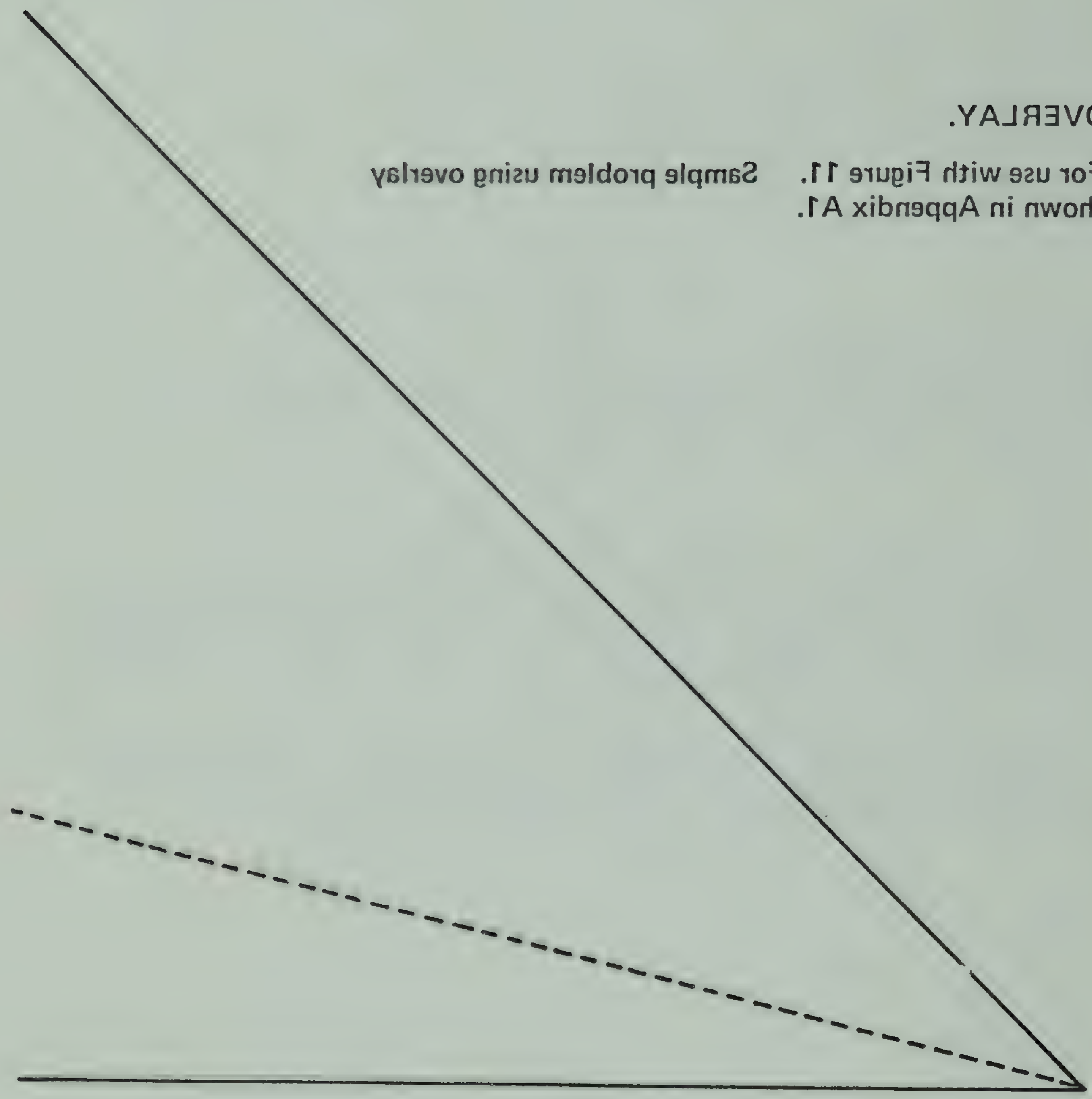
OVERLAY.

For use with Figure 11. Sample problem using overlay shown in Appendix A1.



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